Committee 7

Urodynamics

Chairman

Y. Homma (Japan)

Members

J. Batista (Spain),

S. Bauer (USA),

D. Griffiths (USA),

P. Hilton (U.K),

G. Kramer (Germany),

G. Lose (Denmark),

P. Rosier (The Netherland)

CONTENTS

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Y. Homma,

J. Batista, S. Bauer, D. Griffiths, P. Hilton, G. Kramer, G. Lose, P. Rosier

A. GENERAL REMARKS

I. INTRODUCTION

In preparing this chapter, one of the main goals of the committee has been to present evidence for the ability or inability of urodynamic investigation to improve or at least predict the outcome of treatment for incontinence. In spite of the fundamental importance of urodynamics, the committee has found that for each type of test the evidence is based either on case series (level 4 evidence) or expert opinion (level 5 evidence). For this reason it has not repeatedly restated the levels of evidence, but has graded each of its final recommendations for clinical practice on the basis of these levels of evidence. Inevitably, one of the principal recommendations is for clinical research studies to improve the quality of the evidence.

The lower urinary tract is composed of the bladder and urethra. They form a functional unit to store and evacuate urine. During the normal storage phase, as the bladder is filled with urine, a sensation of filling is perceived at a certain moment and subsequently a desire to void is felt. Normally no uncomfortable sensation such as urgency, pain or discomfort is perceived and no urinary leakage occurs. Competence of the urethra and accommodation of the bladder make it possible to store urine at a low and stable pressure. The low storage pressure insures adequate drainage of urine flow from the upper urinary tract. The normal voiding phase is characterized by the voluntary initiation of micturition followed by forceful and continuous flow with no residual urine. Coordinated relaxation of pelvic floor and external urethral sphincter as well as detrusor contraction contribute to the efficient emptying of the bladder. Urinary flow can be intentionally interrupted by voluntary contraction of urethral sphincter and pelvic floor. Nervous control mechanisms, central and peripheral as well as somatic and autonomic, integrate these functions (Figure 1).

Accordingly, two broad types of lower urinary tract dysfunction may be distinguished: dysfunction of storage and dysfunction of voiding. Clearly urinary incontinence, represents a failure to store urine adequately, but it can be associated with or aggravated by some types of voiding dysfunction of neurogenic, mechanical or functional etiology. Failure to store urine at low pressure or emptying at high pressure may affect upper urinary tract drainage and eventually its function. Occasionally, leakage may occur through channels other than the urethra. This is extra-urethral incontinence.

Urodynamic investigation is a functional assessment of the lower urinary tract to provide objective pathophysiological explanations for symptoms and/or dysfunction of the lower and upper urinary tracts. Urodynamic studies comprise a series of tests. The appropriate test(s) should be selected and performed in an attempt to answer well-defined question(s) on the target functions to be evaluated (Table 1). In the case of incontinence, the most relevant of these tests are directly related to the incontinence itself; that is, they aim to demonstrate involuntary leakage in the test setting. Cystometry with or without simultaneous imaging, ambulatory urodynamics and the measurement of leak point pressures are the primary examples of such tests. Other urodynamic tests have an indirect relation to the incontinence. The information provided by these studies may be useful in establishing etiology and may be clinically important by helping to select the most appropriate intervention. Uroflowmetry, residual urine measurement and pressure-flow studies are examples.

In the clinical work-up of an incontinent patient, urodynamic studies are indicated for the following reasons:

- to identify or to rule out the factors contributing to the incontinence and their relative importance

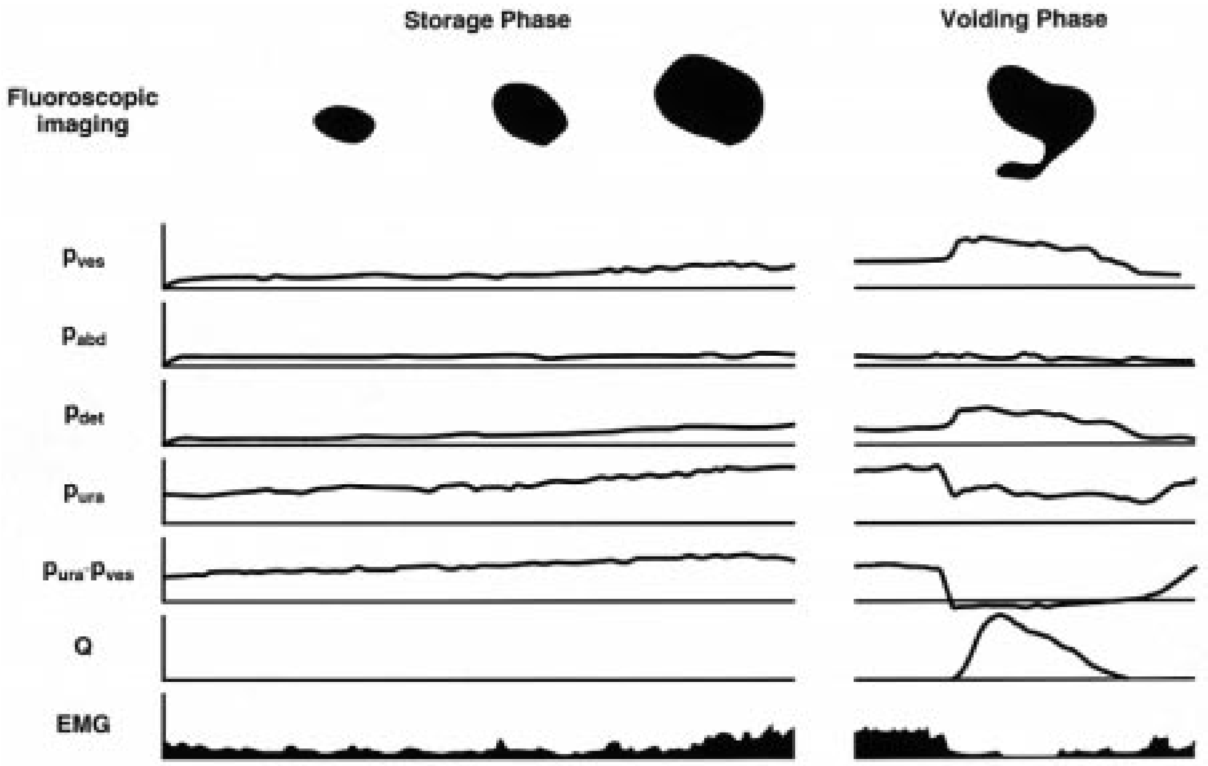


Figure 1 : Illustrative normal urodynamic findings with fluoroscopic imagings. Intravesical pressure (pves), abdominal pressure (pabd), detrusor pressure (pdet: pves-pabd), urethral pressure (pura) measured at the point of maximum urethral pressure, Pura-Pves, urinary flow (Q) and surface electromyography (EMG) during the storage and voiding phases are idealized.

Table 1 : Urodynamic Studies for Urinary Incontinence Assessment

Urodynamic study	Target function to be evaluated	Indicated patients
1. Cystometry	storage function and sensation of the bladder during the filling phase	any incontinent subjects to be investigated for their dysfunctional conditions
2. Urethral pressure measurement	urethral closing forces	subjects suspected of urethral incompetence
3. Leak point pressure measurement A. Detrusor B. Abdominal	urethral competence against pressure generated in the bladder from detrusor or abdominal forces	subjects suspected of neurogenic lower urinary tract dysfunction (A) or urethral incompetence (B)
4. Uroflowmetry, Residual urine measurement	global voiding function	any incontinent subjects (residual) or those suspected of voiding dysfunction (uroflow)
5. Pressure-flow studies	detrusor contractility and bladder outlet obstruction during the voiding phase	subjects suspected of voiding dysfunction
6. Surface electromyography	coordinated relaxation of pelvic floor during the voiding phase	subjects suspected of dysfunctional or dyssynergic voiding
7. Videourodynamics	Simultaneous observation of the morphology and function of the lower urinary tract	subjects with suspected multifactorial etiologies for incontinence or anatomical abnormalities of the lower urinary tract
8. Ambulatory urodynamic monitoring	behavior of bladder (and urethra) and leakage mechanisms during activities of daily living	subjects suspected but not proven to have incontinence or detrusor overactivity on conventional investigations

- to obtain information about other aspects of the lower urinary tract dysfunction
- to predict the consequences of the dysfunction for the upper urinary tract
- to predict the outcome, including undesirable side effects, of a contemplated treatment.
- to confirm the effects of treatment or to understand the mode of action of a particular type of treatment, especially a new one
- to understand the reasons for failure of previous treatments for incontinence

In short, urodynamic studies are indicated to objectively observe lower urinary tract function and dysfunction with the idea of choosing an appropriate treatment for the incontinence and its associated pathology. Basically, the urodynamic study should be performed and reported in accordance with the standards of the International Continence Society (ICS) [1], so as to optimize interpretation and facilitate comparison between different studies. This principle is applied hereafter; however, the chapter is not intended to simply reproduce the ICS standardization report but rather to focus on the clinical relevance of urodynamics to urinary incontinence. It includes recommendations for study procedures, interpretation of study results and the ability to predict treatment. Electrophysiological studies are treated in more detail in chapter 4.

II. THE GENERAL ASPECTS OF URODYNAMICS IN INCONTINENCE ASSESSMENT

Urodynamic investigations must be carried out in a safe, comfortable, and scientific manner, and should be reproducible within the limits of physiological variability, if repeated. This section emphasizes points that are pertinent to all urodynamic studies in the assessment of incontinence [2] [3] These points will be repeated in other sections of this chapter where relevant to the discussion. Further details are available in textbooks [4 - 8]

1. Information prior to study

Prior to the urodynamic investigation a medical history, a physical examination and/or a voiding diary should be taken. Such information is absolutely necessary to select the appropriate studies and to anticipate what events might take place during the urodynamic investigation.

2. General conditions and circumstances of the study

The patient should be informed of the procedures before the studies, preferably by written leaflets but in any event by oral explanation. Any medication that may affect the patient's consciousness or that has been prescribed for lower urinary tract dysfunction should be avoided before the procedure, unless the test is specifically intended to study its effect or there is a clinical reason for not stopping medication. The nature of any such medication and the timing of its administration (especially the last dose) should be noted. Medications that affect lower urinary tract function but have been prescribed for other reasons should be taken into account when interpreting the findings.

The subject should be awake and unanesthetized during the study. In children, studies are sometimes performed under mild sedation. However, this is not desirable and can be avoided if the study is thoroughly explained to them beforehand and if care is taken to distract and calm them during the procedure (see section III.5.e).

The position of the patient during the examination (supine, sitting, standing or ambulatory) needs to be considered and should be specified in the report. In general it may be better to perform bladder filling in the sitting or standing position, or even to change the patient's position, in order to facilitate demonstration of the incontinence. If the position is changed, the pressure transducers (if external) must be repositioned at the reference level (see section I.2.e). In some cases the choice of position may be determined by the patient's condition. For example, if incontinence is due to neurological disease, demonstration of leakage during the examination is usually relatively easy, and it may be simplest to examine the patient supine.

3. The investigator

The investigator plays a crucial role in the urodynamics. The tasks of the investigator include recognition and minimization of artifacts (quality control), communication with the patient regarding sensation and intention, and direction of the whole examination. Quality control requires careful observation of the data as it is being collected. If data quality problems are identified and corrected at this time, a valid examination may be obtained. If not, the study may be uninterpretable. The investigator should talk to patients in a polite and explicit way to facilitate good communication. This is essential so that the patient understands what the investigator requires and the investigator knows how the patient feels and whether the patient is consciously inhibiting the leakage. Also he/she directs the investigation, for example, by repeating a test if the result is unclear, or introducing extra tests if needed to clarify the situation.

Thus, these tasks require diligent scrutiny throughout the progress of the study and understanding of the results while the test is being carried out. Consequently the person conducting the investigations must note and record all relevant events as well as simultaneously interpreting the findings. Simple inspection of traces after the study is completed does not yield a satisfactory interpretation [9].

Formal qualifications for urodynamic investigators have not been developed, but are being considered on a national basis in the UK and in Germany. Provided the person is experienced, the investigator conducting the study may be a physician or a nurse, or a person with a science, engineering or radiology background.

4. Catheters and transducers

Urethral catheters for bladder filling and for pressure measurement should be as small as possible in diameter so as not to interfere with observations of incontinence (leakage) and voiding. However, with a small catheter it may be difficult to drain the bladder when desired. A catheter as small as 6 or 7 French gauge reduces the voiding flow rate in both men [10] and women [11]. Even a 5 French gauge catheter increases the voiding pressure in males [12]. However, the obstructive effect of an 8 French gauge catheter is clinically acceptable in men [13], while a 10 French catheter has a more significant effect [14]. An 8 French gauge catheter tends to increase the measured Valsalva leak point pressure [15]. Thus, for adults, some authorities recommend a maximum catheter size of 8 French gauge, although others permit 10 French gauge. If external pressure transducers are employed, two small single-lumen catheters or a twin-lumen catheter should be used for bladder filling/drainage and intravesical pressure measurement, respectively. Such catheters can be left in place throughout the study so that it can readily be repeated. Optionally, a single urethral catheter with a third channel for simultaneous urethral pressure measurement may be used. If catheter-mounted transducers are employed, the catheter size and the type of transducer (e.g., strain gauge or fibre-optic) are important for interpretation and should be specified in the report. The manufacturer of the catheter and the model number or name should also be specified. Rectal catheters should be similarly described and the name of the manufacturer and the model should be specified as well.

5. Pressure measurement

The principal pressures measured during urodynamic studies are the intravesical pressure, the abdominal pressure and the urethral pressure. The difference between the intravesical and abdominal pressures is called the detrusor pressure. The symbols for these pressures are p_{ves}, p_{abd}, p_{ura} and p_{det}, respectively.

The measurement of pressure is the most important aim of urodynamic tests; nevertheless it is prone to artifacts. To monitor measurement validity, coughing at regular intervals, e.g. every 60 seconds or every 50ml infused, immediately before the examination, during the whole storage phase and immediately after the examination, is therefore essential. Coughing should consistently give similar pressure changes in p_{ves} and p_{abd} (Figure 2).

Currently, pressure is most frequently recorded by the conversion of pressure changes to the electrical properties of a strain gauge transducer. When the strain gauge is outside the body, the pressures that are generated inside the body must be transferred to it. This is possible with fluid-filled catheters and external tubing. Thus, the inserted catheter and connecting tube should be short and flexible, and should not yield to pressure change nor leak at any of connection points. All air bubbles in the system should be meticulously removed.

Transducers to measure pressure can also be mounted on a "microtip" or fiber-optic catheter that can be inserted into the body cavity. Problems related to the tubing system are not important in this case. However, hydrostatic forces inside the abdomen influence the measurement in a variable way, because the pressure reference level is not clearly defined (see *Intravesical pressure*, below) [16]. Another undesirable property of catheter-mounted transducers is that they respond not only to pressures but also to forces exerted on them by solid objects, for example, by contact with the bladder wall. Consequently, intravesical pressures measured by external transducers may differ from those measured internally by 20 cm H_2O or more [17].

Alternatively the pressure-measuring catheter can be air-filled; the catheter is provided with a small air-filled balloon to prevent entry of liquid from the bladder and is connected to external transducers by an air-filled connecting tube. As for catheter-mounted transducers, the pressure reference level is not clearly defined. The balloon must not be over-inflated (see *Abdominal pressure*, below).

In clinical urodynamic practice, absolute pressure values sometimes seem less important than pressure patterns. However, the reliability of the absolute value plays an important role in the control of measurement quality. In many clinical situations furthermore it is essential to ensure that the measured pressures are correct. For instance, when comparisons with reference values from the literature are used in clinical decision-making; or when cystometric values before and after treatment are compared in outcome analysis based on multicenter data; or when longitudinal observations on

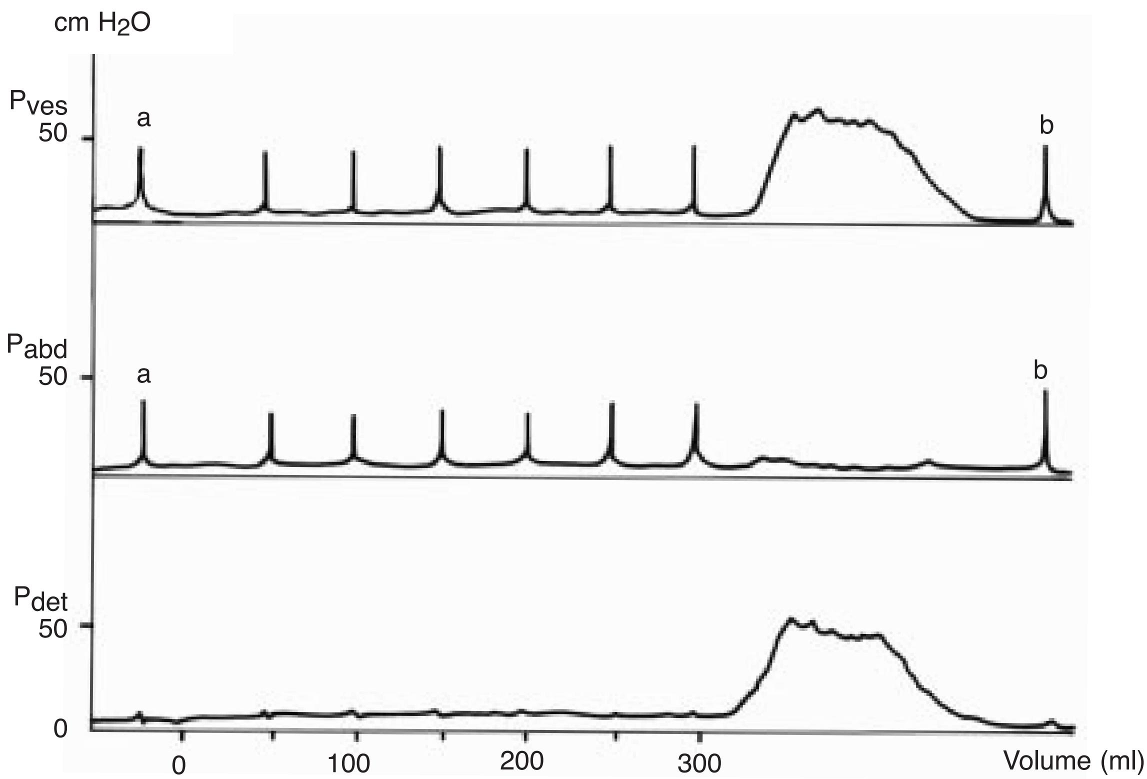


Figure 2 : IIdeal cystometric traces with coughing at regular intervals of 50ml filling. Note coughs before starting (a) and after ending the test (b).

a single patient are compared. Specific examples include leak point pressure measurement and grading of bladder outlet obstruction by pressure-flow analysis.

a) Intravesical pressure

In the physical sense p_{ves}, which is the pressure in the liquid contained within the bladder, is a true pressure. This pressure is the height, above a given reference level, to which the liquid would rise in an open catheter puncturing the bladder. p_{ves} consists of 2 components: a contribution from the internal forces in the bladder wall (p_{det}), and a contribution from the organs surrounding the bladder (p_{abd}):

i.e., $p_{ves} = p_{det} + p_{abd}$.

The standard reference level for all pressure recording is defined as the upper border of the pubic symphysis. If an external pressure transducer is used with water-filled connecting tubes, it should be zeroed to atmospheric pressure and placed at this level during the procedure. If a catheter-mounted transducer or an air-filled balloon catheter is used, the reference level for p_{ves} is at the level of the transducer or the balloon. Thus its relation to the pubic symphysis not known exactly. In these cases the transducer or balloon should be zeroed to the atmospheric pressure prior to insertion.

b) Abdominal pressure

p_{abd} represents the net effect of the forces exerted on the bladder by surrounding organs. Measuring the pressure inside the rectum or the vagina [18] [19] approximates p_{abd}.

If an external pressure transducer with water-filled tubes and catheter is used to measure p_{abd}, it should be placed at the same level as the p_{ves} transducer and zeroed in the same way, so that the same reference level is employed. If a catheter-mounted transducer is used, the reference level for p_{abd} is at the position of the transducer and is unlikely to be the same as for p_{ves}. This in itself can be a source of artifact.

If a water-filled balloon is inserted in the rectum for pressure measurement it is essential not to overinflate it (to no more than 50% of nominal capacity), in order to avoid an artificially elevated p_{abd}. The balloon may be punctured to prevent this possibility. Accurate measurement is not possible unless the vagina or the anal sphincter forms a tight seal around the catheter. In this regard intravaginal recording appears to be less reliable [20] unless the catheter is high in the vaginal vault. Whatever the means used to measure the abdominal pressure, its accuracy should be monitored throughout the study, by ensuring that transient pressure excursions due to coughing are recorded equally in p_{ves} and p_{abd}. Even if these conditions are met, slow rectal contractions, or an elevated tone in the rectal wall, may occur and lead to an artificially elevated and/or fluctuating value for p_{abd}.

c) Detrusor pressure

Rearranging the above equation shows that the detrusor pressure is defined as

$$p_{det} = p_{ves} - p_{abd}.$$

Therefore the detrusor pressure can be calculated from measurements of p_{ves} and p_{abd}. It represents the effect of the active and/or passive forces generated by the detrusor muscle, separate from any external pressures applied to the bladder wall. In other words it eliminates the effects of coughing and straining and shows what the detrusor itself is doing. It is difficult to distinguish the effects of straining from detrusor contractions if only p_{ves} is measured [21].

If recording is started with a nearly empty bladder, one expects the forces in the bladder wall to be very small. Consequently, provided the zeroing has been carried out correctly, p_{ves} and p_{abd} should be nearly equal and p_{det} close to zero. With catheter-mounted transducers, because the abdominal and intravesical pressures are referenced differently and to unknown reference levels, this may not be exactly correct [17]. The apparent initial value of p_{det} may be slightly greater than zero or slightly negative.

d) Urethral pressure

The pressure in the urethra may be measured during storage and/or during voiding, the former being the primary concern in this chapter. There are difficulties in the definition and measurement of p_{ura} during storage, because the urethra is collapsed during the storage phase. It contains no fluid and so p_{ura} cannot represent a true pressure in a physical sense.

Further consideration has shown that p_{ura} is the fluid pressure that would hypothetically be required to force open the collapsed urethra and so allow urine to flow [22]. The method of measurement that conforms most closely to this definition is the perfusion or Brown-Wickham method [23] [24] In this method the liquid is slowly infused into the urethra through the sidehole port on the catheter. To accommodate the liquid, the urethra has to be forced open very slightly. The fluid pressure needed to do so is measured. The urethral pressure measured in this way varies from point to point within the urethra. Thus, a graph of urethral pressure against distance along the urethra can be drawn, the urethral pressure profile (UPP). By definition, the urethral pressure should be independent of the orientation of the catheter sidehole or transducer within the urethra. With some methods of measurement however the pressure reading does depend on the orientation (see section II.**2.a**). This is also a sign that the urethral pressure is impossible to measure correctly (by such methods) in clinical practice. Choosing a very flexible catheter [22] and a lateral orientation for the sidehole or catheter-mounted transducer minimizes the systematic error. The subtraction of p_{ves} from p_{ura} produces the urethral closure pressure.

6. Detection of Leakage

Methods of detecting leakage from the bladder have not been standardized despite their critical importance in the evaluation of incontinent subjects. An electrical method of detecting urine in the urethra by measuring distal electric conductance has been shown to be a sensitive index of urine leakage [25] Pads incorporating wire grids or temperature-sensitive diodes have been used to detect urinary leakage by the change of electric resistance or temperature. If videourodynamics is available, fluoroscopy provides a way of detecting leakage of X-ray contrast. A flowmeter placed below the patient may record leakage. In most cases, however, demonstration of a leakage relies on naked-eye observation by the investigator. If there is substantial loss, detection is easy, but loss of a few drops may be overlooked. A dry piece of cotton cloth, preferably dark-green in color, or a simple paper towel applied to the orifice [26] may help the investigator detect the urine loss.

7. Equipment for Urodynamics

Urodynamic instruments intended for pressure measurement should be equipped with at least 2 pressure-measuring channels, for p_{ves} and p_{abd}, and a means of calculating and recording p_{det}. The p_{det} channel should be capable of recording slightly negative as well as positive values. A minimum sampling rate of 10 data points per second is probably necessary, although higher sampling rates have been recommended [27]. Depending on the complexity of the testing, urodynamic instruments may also have channels for infused volume, urethral pressure, voiding flow rate, voided volume, or EMG, and a means of displaying and recording these measurements together with simultaneous images. Despite such sophistication some newer systems do not allow post-processing of "automatically" analyzed data, and use recording paper with a narrow width and/or height, which can make the traces difficult to read. To rule out artifacts the examiner should inspect the traces and compare them to the data that have been automatically analyzed

The manufacturers provide data on accuracy of equipment but there is no external organization that monitors the technical and clinical data quality. Studies of intrinsic clinical and technical 'robustness,' determined by comparing different measuring techniques, are rare [28 - 30]. Consequently, it is not certain whether the data obtained on urodynamic equipment from different manufacturers are truly interchangeable [31]. It has also not been shown whether the data from similar equipment used in different departments are interchangeable. The intrinsic technical quality of the urodynamic equipment on the market is probably adequate; however, it should be remembered that no objective quality control exists.

The users of equipment should carefully maintain the machine in good condition, and the calibration of uroflow and pressure transducers should be checked periodically, for example, every month. If the filling volume is derived from a weight transducer this too should be checked regularly. If it is derived from counting the revolutions of a peristaltic pump, it is probably necessary to recheck or recalibrate the pump for every test, following the manufacturer's instructions.

8. Description of urodynamic study conditions

The procedures for urodynamic studies are so variable in their details that it is important to report the study conditions, so as to allow others to judge the quality of the investigations. Shown in Table 2 are the basic study conditions that should be reported in scientific articles dealing with urodynamic aspects of urinary incontinence.

9. Interpretation of study results

Urodynamic test results should be interpreted and integrated with other clinical findings to make an appropriate clinical decision. Different urodynamic findings may be present with a given clinical presentation, and the same urodynamic observations may be made in the presence of different symptoms [32 - 37]. The results are sometimes expressed in terms of values of selected variables. In order to attain accurate interpretation at the individual level, however, the whole chart should always be taken into account.

a) Variability in urodynamic data

Lower urinary tract function has a certain physiological variability. This variation and methodological inconsistency inevitably limit the reproducibility of urodynamic investigation. For instance, uroflowmetry in symptomatic elderly men shows considerable variation in maximum flow rate [38]. Inter- and intra- observer variability in reading the maximum flow rate from a given flow curve is typically 1 ml/s or more [39]. Repeated cystometries demonstrate a tendency for capacity or volume to first contraction to increase [40 - 41]. In a 3-way drug trial in women with "detrusor instability", 5/20 (25%) changed from unstable to stable after 3 weeks on placebo [42]. When cystometrograms were repeated in girls (mean age 8 years), 10% changed from stable to unstable and 14% changed from unstable to stable, from the second to the third study [43]. The proportion showing detrusor overactivity declined in successive filling cystometries, with the results of the third study showing the strongest association with symptoms [44].

b) Urodynamic classification of voiding dysfunction

When reporting or reviewing information about a urodynamic study, there is a certain minimum amount of information about the storage and voiding phases that should be described according to a well-defined terminology. The classification of lower urinary tract dysfunction shown in Table 3 is derived from the ICS, but several others have been proposed [45]. In some cases (e.g. pressure-flow studies in men) borderline (cut-off) values have been established, but in others further investigations will be needed to achieve this.

If the dysfunction observed during a urodynamic investigation is caused by an anatomical or neurological abnormality, it is advisable to add 'secondary to...' followed by a description of the dysfunction. It is sometimes better to state that the dysfunction is 'in combination with ...', if the dysfunction is of an unexpected type and/or if it is not clear whether it is attributable to the presumed primary disease.

Table 2 : Basic Study Conditions to be Documented in Scientific Communications

- Investigator
- Circumstances during study
- Patient conditions
  - sedation, medication, position, provocation
- Equipment
  - type, calibration
- Pressure measurement
  - reference level, transducer
- Catheter
  - size, side-holes, type for microtip transducer catheter, number of channels, manufacturer
- Fluid
  - infusate, rate of infusion, temperature
- Method of leakage detection

Table 3 : Urodynamic Classification of Lower Urinary Tract Dysfunction

Storage Phase	Voiding Phase
• Detrusor activity	**• Detrusor activity**
- normal (stable)	- normal
- overactive phasic terminal neurogenic idiopathic	- underactive - acontractile
• Bladder sensation	
- normal	
- increased (hypersensitive)	
- reduced (hyposensitive)	
- absent	
• Bladder capacity*	
• Compliance*	
• Urethral function	**• Urethral function**
- normal	- normal
- incompetent	- abnormal

**) No classification terms are given (see text 2.1.3. and 2.1.4.)*

c) Urodynamic definitions of the types of incontinence

The symptom of incontinence is usually the result of a complex spectrum of anatomical and physiological disorders of the lower urinary tract 46 47. Overactive detrusor contractions vary in duration and amplitude and may occur with or without concomitant urgency. Bladder sensation may be aroused by involuntary contraction of the detrusor or by other ill-defined factors. Urethral competence is maintained by urethral and para-urethral factors that become deficient in stress incontinence 48. These deficiencies are reflected in a low maximum urethral closure pressure (MUCP, section II.2.a), a low leak point pressure (LPP, section II.3), a low pressure transmission ratio (PTR, section II.2.b), or a reduced sphincter thickness, or in pronounced urethral hypermobility and bladder descent. There is a continuous gradation of severity in these abnormalities, which is coupled with or confounded by related functions and dysfunctions. Therefore for many urodynamic variables it is impossible to provide fixed cut-off values on a clear scientific basis, so as to define any specific pathologic feature.

Nevertheless urodynamics must be taken as the gold standard that other investigations can rely upon, because incontinence is a dysfunction of the lower urinary tract and only urodynamics can describe the function or dysfunction. For this reason an explicit and unambiguous urodynamic definition of urinary incontinence and associated findings is needed.

Stress incontinence denotes a symptom and a sign: the patient's statement of involuntary loss of urine during physical exertion and the observation of leakage from the urethra synchronous with physical exertion (e.g., coughing), respectively. Urge incontinence is a symptom: an involuntary loss of urine associated with a strong desire to void (urgency). Terms for the corresponding urodynamic observations are currently under reconsideration. *Urodynamic stress incontinence* and *detrusor overactivity incontinence*, respectively, are used in this chapter. Urodynamic stress incontinence is the urodynamic observation of involuntary leakage in the absence of a detrusor contraction, with elevated intravesical pressure. Detrusor overactivity incontinence is the urodynamic observation of urine loss caused by an involuntary detrusor contraction. It may ultimately be necessary to further elaborate the terminology, since different types of urge incontinence with different etiologies exist 49 - 51. Combinations of these types of incontinence, mixed stress and urge incontinence, are frequently encountered (Table 4).

Other types of incontinence are symptomatic descriptions. Various underlying urodynamic observations are possible 52. Previously, "reflex incontinence" was defined as the loss of urine due to detrusor overactivity and/or involuntary urethral relaxation in the absence of the sensation of the desire to void. "Overflow incontinence" was defined as any involuntary loss of urine associated with over-distension of the bladder. These terms are currently being reconsidered and will probably no longer be recommended.

Nocturnal enuresis means involuntary loss of urine during sleep. It becomes clinically relevant only after the age of, for example, 5-6 years, although it is not uncommon for children to wet at night (with decreasing prevalence) until puberty.

d) Association of symptoms and urodynamic finding

It has been argued that symptoms and urodynamic findings do not match. Jensen et al reviewed 29 articles between 1975 and 1992 that addressed the clinical evaluation of urinary incontinence, and analysed the diagnostic performance of symptoms 53. They found that the sensitivity and specificity of symptoms suggestive of either of 3 final urodynamic findings (Urodynamic stress incontinence, detrusor overactivity incontinence, or both) were 0.48 to 0.91 and 0.51 to 0.66, res-

Table 4 : Terms related to urinary incontinence that either do not (A) or do (B) need urodynamic confirmation

A	
Urinary incontinence as a symptom	the complaint of involuntary urine loss
Urinary incontinence as a sign	the objective demonstration of urine loss
Stress incontinence as a symptom	the complaint of involuntary loss of urine during coughing, sneezing, or physical exertion
Stress incontinence as a sign	the observation of urine loss from the urethra synchronous with coughing, sneezing, or physical exertion
Urge incontinence	the complaint of involuntary loss of urine associated with a sudden, strong desire to void (urgency)
Mixed incontinence	the complaint of both stress and urge incontinence
B	
Urodynamic stress incontinence	the involuntary leakage of urine during raised intravesical pressure secon dary to increased abdominal pressure, in the absence of a detrusor contraction
Detrusor overactivity incontinence	the involuntary leakage of urine during raised detrusor pressure resulting from detrusor overactivity. In patients with sensation, urgency is experienced before the leakage episode.
Urodynamic mixed incontinence	both urodynamic stress incontinence and detrusor overactivity (± incontinence)
Detrusor overactivity	the involuntary detrusor contractions during the filling phase at any time prior to "permission to void" being given. The contractions may be of any size and may be spontaneous or provoked. If contraction is observed without leakage, it may be only suggestive of detrusor overactivity incontinence. The current terminology does not distinguish overactivity accompanied by the sensation of urgency from sensation-free overactivity.

pectively, depending on the type of incontinence (Table 5). Analysis of selected or more homogenous populations did not significantly alter the validity. More recent studies on this subject have given similar results [33], [54 - 59]. To improve prediction most of them utilised non-urodynamic variables and a standard questionnaire or frequency-volume chart to assess the symptoms. Using voiding frequency and voided volume retrieved from frequency-volume charts, one study gave a nomogram for the probability of detrusor overactivity [60]. However, the validity of the nomogram was not confirmed in a following study [61]. The mean voided volume in frequency-volume recording was significantly smaller in detrusor overactivity incontinence (151ml, n=23) than in urodynamic stress incontinence (220ml, n=73), but there was a substantial overlap [62]. The symptom score for leakage associated with physical activity was higher for stress incontinence but other symptom scores addressing nocturia, frequency, urgency, urge incontinence or incomplete voiding did not differ between stress and urge incontinence [63]. In practice, positive predictive value and negative predictive value are of more clinical significance. Stress incontinence as the dominant symptom has a positive predictive value for urodynamic stress incontinence of more than 70% (Table 5). However, the positive predictive value of overactive bladder syndrome (frequency, urgency and/or urge incontinence) for detrusor overactivity was only 54% [64].

Thus, symptom-based diagnosis is misleading as a predictor of detrusor overactivity. It is felt, however, that stress incontinence as the dominant symptom with auxiliary evidence is specific to and predictive of urodynamic stress incontinence, especially in patients without prior surgery [55], [57]

10. Summary

- A urodynamic investigation is a functional assessment of the lower urinary tract, usually performed to provide objective pathophysiological explanations of symptoms and/or dysfunction
- Urodynamic investigations should be conducted safely in a scientific and respectful manner.
- Urodynamic measurements are prone to artifacts. They should be carefully identified and eliminated during the study whenever possible. Accurate description of study conditions and methods is essential.

Table 5 : Value of patient history for predicting urodynamic findings

Author	year	Method	Sample size	Urodynamic stress incontinence			Detrusor overactivity incontinence		Mixed incontinence	
				STV	SPT	PPV	STV	SPT	STV	SPT
Jensen	1994	Review		0.91	0.51	0.75	0.74	0.55	0.48	0.66
Handa*	1995	A	101	0.77	0.44	0.52				
Handa*	1995	B	101	0.82	0.59	0.70				
Haeusler	1995	C	1938	0.56	0.45	0.88	0.62	0.56		
Cundiff	1997	D	535	0.44	0.87	0.87	0.71	0.41	0.68	0.48
Videla	1998	E	72			0.82				
Diokno*	1999	F	76	0.83	1.0	1.0				
James	1999	G	555			0.81				
Lemack*	2000	H	174			0.92				

Abbreviations: STV; sensitivity, SPT; specificity, PPV; positive predictive value
*Predictive value for type II stress incontinence
A: limited evaluation (no urodynamics required) by AHCPR criteria [128]
B: stress incontinence dominant, no prior surgery, positive stress test, hypermobility, residual < 50ml, age < 65, no prolapse
C: Gaudenz Incontinence questionnaire
D: stress incontinence dominant
E: stress incontinence dominant, positive stress test, residual < 50ml, maximum functional capacity > 400ml
F: stress incontinence dominant, no prior surgery, hypermobility, no grade 4 prolapse and residual < 200ml
G: stress incontinence without bladder filling symptoms H: stress incontinence dominant, no prior surgery

- Appropriate examinations should be selected so as to achieve the best possible assessment of the patient's condition.
- The investigator should be well versed in the procedures and interpretation of urodynamic studies, and understand their clinical relevance in each patient.
- The limitations on the accuracy and the interchangeability of study results should be kept in mind during interpretation.

11. Future study areas

- Development of formal qualifications for investigators through certification of courses in the practice of urodynamics.
- Comparative studies of different methods of detecting urine loss during a urodynamic study.
- Standardization of equipment, instrumentation, techniques, and documentation, and adoption of a standard file format to enable interchange of results
- Determination of physiological, technical and interpretational variability for urodynamic study results.
- Better definition of the pathophysiological conditions underlying the types of incontinence and the corresponding urodynamic observations, and further refinement of the recommended terminology to reflect this.

B. URODYNAMIC STUDIES

I. CYSTOMETRY

The core test of a urodynamic investigation is cystometry. Cystometry is the continuous measurement of the pressure/volume relationship of the bladder to assess sensations, detrusor activity, bladder capacity and bladder compliance. In the context of this chapter, an important aim of cystometry is to reproduce the symptom of incontinence. For this purpose, maneuvers intended to provoke either urodynamic stress incontinence or detrusor overactivity incontinence are important.

1. Technical aspects

The bladder is most commonly filled through a transurethral catheter. The bladder can be catheterized suprapubically or it can be filled solely via (forced) renal excretion [65]. Bladder filling may be carried out with or without preliminary drainage of residual urine; whether or not this is done should be stated. If catheters are introduced using an anesthetic agent, the effect must be taken into account in the interpretation. It is important to keep in mind that *any* variations in technique may affect study results.

Historically, both liquid and gas have been used as the filling medium. Gas (carbon dioxide) is usually infused at a high rate (> 100 ml/min), allowing rapid and inexpensive performance of a study. However, it is unphysiologic and compressible, and easily provokes detrusor overactivity (see below) [66]. Rapid filling may also lead to erroneous diagnosis of reduced bladder compliance. It is not suitable for studying voiding, and leakage is very difficult to detect due to invisibility of the gas. Gas cystometry is not reliable [67] and thus not recommended.

The liquid filling medium may be physiologic saline, water, or radiographic contrast. The physical properties of the liquid, its acidity, the type of contrast medium and the concentration of ions such as K^+ and Ca^{++} may affect detrusor overactivity [68 - 70]. The temperature of the liquid is usually either room temperature or body temperature. Traditionally, the filling rate is referred to as 'fast' (> 100 ml/min), 'medium' or 'slow' (< 10 ml/min). Natural bladder filling is on average 1-2 ml per minute, although diuresis at up to 15 ml/min is possible for short periods. Therefore, even 'slow' urodynamic filling is already non-physiologic filling rates. For children a rate above 10% of predicted or known bladder capacity per minute might be considered a 'fast' filling rate. 'Fast' filling is considered to be provocative of detrusor overactivity (see below) and any unphysiologically 'fast' filling tends to produce lower bladder capacity and lower compliance. Stepwise cystometry, with 'fast' intermittent volume increments, has been used in research settings to determine the viscoelastic properties of the detrusor [71 - 73]. Particularly if 'slow' filling is used, the volume of liquid in the bladder may be considerably larger than the measured volume (i.e., the volume introduced) because of urine production during the examination.

Some authors advise that 'fast' filling rates should be used if no detrusor contractions can be elicited in the individual suffering from urge incontinence [74]. This may conflict with the aim to reproduce the symptoms experienced in daily life (see over-provocation, below). Ice water testing can be used to demonstrate the existence of a temperature-sensitive reflex detrusor contraction mediated by afferent C-fibers, The reflex is interpreted as evidence for a neurogenic abnormality [75 - 79]. Instructing patients not to voluntarily inhibit the urge to void, but merely to communicate sensations, increases the efficacy for identifying detrusor contractions. In a prospective study of 42 patients referred for irritative symptoms, a randomized double blind protocol asking patients to either inhibit or not inhibit micturition during cystometry showed a statistically significant increase in the presence of involuntary contractions when patients were instructed not to inhibit micturition [80].

Other provocative tests intend to demonstrate detrusor overactivity or urge or stress incontinence, include coughing (Figure 3), change of position from supine or sitting to standing, filling in the standing position, running water, handwashing, and waiting with a full bladder (sometimes when sitting on a commode). In women with incontinence, filling cystometry in the supine position without provocation demonstrates "detrusor instability" in only 38% of bladders shown ultimately to be unstable. In a further 29%, "detrusor instability" is provoked by a change of posture, and in 33% it is provoked by coughing [81].

Handwashing is another potent provocation of "detrusor instability" [82]. In women with symptoms of urge incontinence, sitting on a commode with a full bladder for 1 minute was the most provocative maneuver for "detrusor instability", being about 27 times more provocative than remaining supine [83]; the second most provocative maneuver was handwashing for 1 minute. However, these two results were based on carbon dioxide cystometry, a non-recommended method. In children, "slow" bladder filling while distracting their attention should help to evoke "detrusor instability" [84]. Since over-provocation may reveal overactive detrusor function of no clinical significance, as observed in symptom-free volunteers, the results of provocative testing must be judged in relation to symptoms.

Bladder sensation during cystometry is judged on the basis of the volume in the bladder at patient's 'first sensation of bladder filling', 'first desire to void' and 'strong desire to void'. Urgency is a compelling desire to void. A strong desire to void or urgency — depending on the patient and the investigator — usually defines the urodynamic bladder capacity (see section II.1.c *Description of study results* below). Methods of questioning the patient regarding these sensation parameters are only vaguely defined. Their reproducibility is not well documented. However, one group found that repeated bladder filling increased sensation intensity, which was more consistently related to intravesical pressure increase than to bladder volume [85]. Providing the patient with a push-button system to record sensations appears a promising way of standardizing the testing of sensation and increasing reproducibility [86].

When no equipment is available or referral is not feasible, "simple cystometry" (Figure 4) is an option [87, 88]. For the detection of detrusor overactivity, taking multichannel cystometry as the standard, simple cystometry is reported to have specificity and sensitivity of over 80% in elderly patients [89 - 91]. In both geriatric and female populations, the rate of detection of detrusor overactivity was not substantially different in simple and multichannel investigations [90, 91].

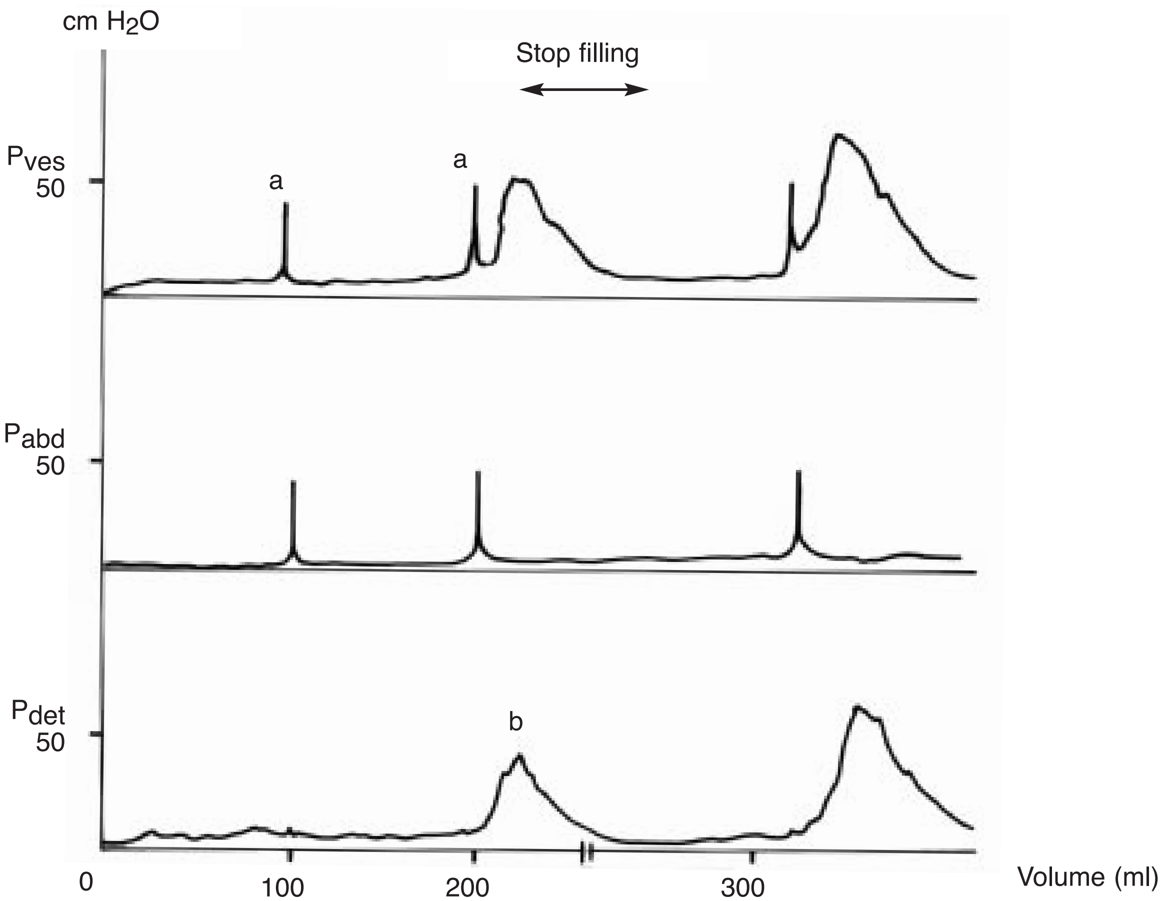


Figure 3 : Cough (a) provoked involuntary contraction (b) at 230ml.

2. Safety

Screening of urine for bacteriuria at the time of the test is important to rule out unrecognized infection. Antibiotics administered at or just after the study, are at the discretion of the investigator.

The main risks of cystometry are those associated with urethral catheterization. Dysuria (painful voiding) occurs in some patients after urodynamic testing, but usually disappears within 48 hours [92]. The technique used for catheterization, and for handling of transducers and connecting tubes, varies in different centers from clean to sterile. It is not known whether these variations have any effect on the infection rates. In any case, appropriate aseptic techniques should be used.

3. Description of study results

The study results are expressed in terms of bladder volume at various sensations or the amplitude and duration of detrusor pressure activity. Detrusor overactivity is defined as an involuntary detrusor contraction during the filling phase. It may be spontaneous or provoked and of any magnitude and duration. Sub-classification of overactive detrusor function is described below. Cystometric capacity is determined differently in different types of dysfunction. In the normal case it is the volume at which the patient states that he/she can no longer delay micturition because of strong desire to void or urgency. In urge incontinence it is the volume at which involuntary voiding occurs. In the absence of sensation cystometric capacity is the volume at which the investigator decides to terminate filling. Occasionally filling has to be terminated because of patient discomfort. The event that determines cessation of filling should be reported. Compliance is defined as volume increment per detrusor pressure increment (ml/cm H_2O). Note that all volumes should refer to the volume actually present in the bladder, not the volume introduced, and may have to be estimated.

4. Interpretation of abnormalities

In the interpretation of detrusor activity during filling, the amplitude and the duration of the contraction and the intravesical volume at which the contraction occurs should be taken into account. It should be remembered that no method of monitoring attempted suppression or inhibition has been standardized. If flow or leakage occurs, the pressure attained does not fully represent the strength of the contraction or its clinical significance.

Observation of detrusor overactivity by itself is suggestive of underlying abnormality but is not conclusive, because it is frequently observed in healthy volunteers 65, 93, especially if observations are continued for long periods, for example during ambulatory monitoring (see section II.8.c). Detrusor overactivity needs to be interpreted in the light of symptoms and signs. Observation of involuntary detrusor contraction that leads to leakage (detrusor overactivity incontinence) is more conclusive because it is clearly abnormal. However, it still requires interpretation in the light of the patient's history.

Traditionally, detrusor overactivity has been subdivided into "detrusor hyperreflexia" (overactivity with a relavant neurological condition) and "detrusor instability" (overactivity with no definite cause) 65. These terms have been replaced by nerogenic detrusor overactivity and idiopathic detrusor overactivity, respectively. A more detailed classification of overactive bladder function, based mainly on observations of urodynamic patterns, has been proposed 94, 95. In this classification scheme *phasic detrusor instability* describes phasic involuntary contractions of the detrusor during bladder filling; it is found commonly in younger patients with urge symptoms and no overt neurological disease. *Uninhibited overactive bladder* describes the observation of a single involuntary detrusor contraction that terminates bladder filling and causes leakage, often accompanied by reduced sensation of bladder filling; it is a common cause of urge incontinence among elderly people and appears to be associated with cortical dysfunction 50 51 94 95. These conditions have been adopted by the ICS as phasic detrusor overactivity and terminal detrusor overactivity, respectively.

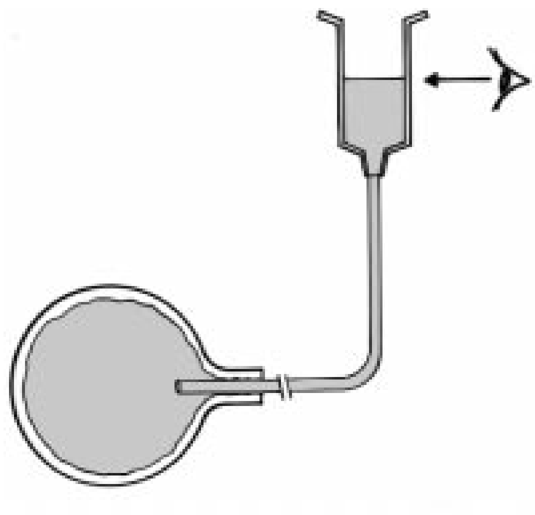
Borderline (cut-off) values of volume or pressure for the various sensation are at present undetermined. However the sequence of sensations is fairly reproducible 96. Similarly, exact reference values for normal urodynamic capacity are not available, because they depend on the technique of the investigator. The actual capacity is the total volume of fluid a patient will hold before voiding and is somewhat dependent on the rate of infusion, but changes also with repeated filling 41. As an approximate guide, a capacity of about 300-600 ml is normal in adults. For children 30 ml+30 ml x age (in years) is an appropriate capacity 97. As another approximate guide, 60 ml + 60 ml x age (in years) for children less than 2 years old and 180 ml+15 x age (in years) for children over 2 years old have been recently proposed 98.

Bladder compliance is influenced by infusion rates, position of the patient, the volume of fluid in the bladder and the part of cystometrogram used for compliance calculation. There is insufficient data to precisely define cut-off values between normal or abnormal compliance, but values in the range 12.5 to 30 ml/cm H_2O have been suggested as the lower limit of normal 99. Among healthy adults, compliance is higher in women than in men 100]. Dynamic analysis of compliance, taking into account the multiple phases of bladder filling curve, has been suggested 101. In children, the compliance determined by urodynamic investigation is an important outcome parameter 102 - 104. If abnormally low compliance is observed, cystometry at a lower filling rate may lead to a different result.

Despite the differences of opinion mentioned above about the interpretation of the cystometrogram, the 'archetypal' cystometric patterns of a normal detrusor, detrusor overactivity, and low compliance are straightforward and simple to understand. It is useful to judge a cystometrogram according to these landmarks 105, even though only approximate normal values are known (Figures 4 and 5).

5. Indication for cystometry in incontinent patients

Cystometry is the basic urodynamic evaluation for incontinent patients. It may be indicated to evaluate bladder function prior to therapeutic approaches, including medical and in particular surgical interventions. Urodynamic assessment prior to surgery not only allows an accurate diagnosis but also enables a discussion with the patient of any problems that might arise



Figures 4 : Schematic diagram of simple cystometry. The height above the symphysis of the fluid meniscus in a syringe indicates intravesical pressure.

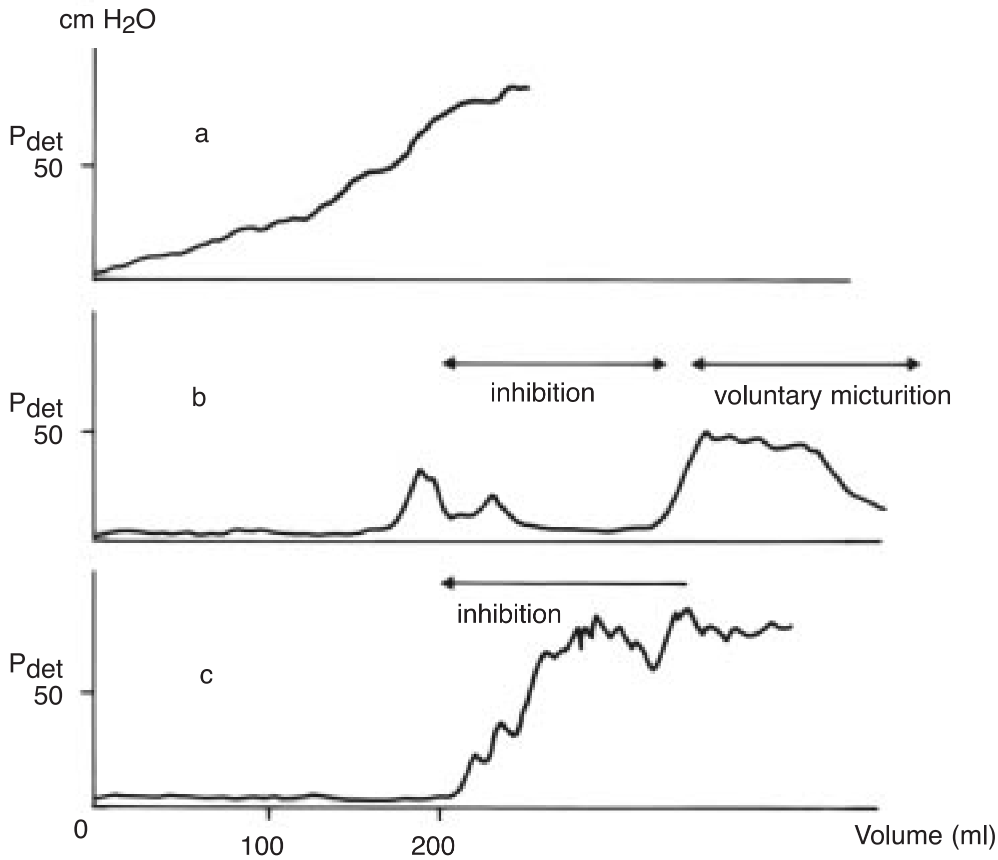


Figure 5 : Diagrams to show low compliant bladder (a), overactive detrusor with phasic pressure waves that the patient can suppress (b), and overactive detrusor with subsequent leakage that the patient cannot suppress (c).

after intervention because of other co-existing abnormalities.

From a health planning perspective, multichannel urodynamic assessment is more expensive than a cough stress test plus simple cystometry, and it appears to have a similar sensitivity for the diagnosis of urodynamic stress incontinence 106. However, cost-effectiveness, defined in terms of treatment outcome, was not considered in this study.

6. Good urodynamic practice

- When filling cystometry is performed, intravesical (p_{ves}) and abdominal pressures (p_{abd}) should be measured and detrusor pressure (p_{det}) should be calculated; all 3 pressures should be recorded
- Initial values of p_{ves} and p_{adb} should be plausible; the initial value of p_{det} should be close to zero
- If catheter-mounted transducers are used, the initial value of p_{det} may differ from zero by up to a few cm H_2O.
- p_{ves} and p_{abd} should respond equally to coughs; frequent cough checks are essential
- Filling rates should be chosen according to the aim of the investigation
- The posture of the patient during the test is important; it is unlikely that incontinence will be consistently demonstrated in the supine position only
- To demonstrate incontinence, provocative maneuvers designed to elicit leakage should be performed
- The investigator's awareness of the patient's sensations and the instructions given to the patient are critical parameters.

7. Predictive value of filling cystometry for treatment outcome

Investigations have repeatedly shown that the success rate for surgery for stress incontinence is higher in women without detrusor overactivity 107. A recent paper failed to show any difference in outcome in a group receiving full urodynamics as opposed to simpler methods 108 Such investigations have usually included women both with and without symptoms of urgency and urge incontinence. An important question is therefore whether filling cystometry allows more precise selection of a group of stress-incontinent patients who will respond particularly well to surgery *in spite of* concurrent urge symptoms. Two papers suggest that surgery successfully cured urge symptoms in 91% of those with low-amplitude detrusor overactivity (peak detrusor pressure < 15 cm H_2O), but was less successful in those with no observable detrusor overactivity (cure rate 39%) [109] or those with high-amplitude overactivity (cure rate 28%) or low compliance [110]. These observations suggest an important place for filling cystometry in women with stress incontinence and urge symptoms.

Among men or patients with neuropathy detailed urodynamic examination is usually considered an essential basis for rational management. Nevertheless few studies have been undertaken to evaluate the utility of cystometry. For men, preoperative filling cystometry was unable to predict incontinence after radical prostatectomy [111] Treatment is usually conservative or medical for the elderly.

8. Summary

- Filling cystometry is the basic test for examining the aspects of bladder function concerned with the efficient storage of urine.
- Good patient-observer communication throughout the study is mandatory
- Analysis of the cystometrogram is based on pattern recognition, and evidence-based quantification of the cystometric observations is not yet possible.
- Artifacts produced by catheterization, infusion or provocation should be taken into account in the interpretation.

9. Future study areas

- Quantification of observations during cystometric investigation to achieve reliable, interchangeable and clinically relevant information
- Assessment of the reproducibility of these observations in terms of clinical outcome measurements.
- Clinical significance of involuntary detrusor contractions observed during bladder filling that do not reproduce symptoms, e.g. because they are not accompanied by sensation or leakage
- Improved methods of assessing bladder proprioception
- Confirmation of the ability of filling cystometry to predict outcome of surgery among women with stress incontinence and urge symptoms

II. URETHRAL PRESSURE MEASUREMENT

Continence is dependent on the powers of urethral resistance exceeding the forces of urinary expulsion [112, 113]. In order to maintain continence the urethral lumen should seal completely; this hermetic effect is dependent upon the softness and compressibility of the urethral wall [114]. Together, these properties determine the intraluminal *urethral pressure*. The *urethral closure pressure* represents the difference between the urethral pressure and the simultaneously recorded intravesical pressure, and conceptually, therefore, it represents the ability of the urethra to prevent urine leakage.

Urethral pressure measurements may be taken from all points along the urethra in steady-state conditions, and are reproduced in the form of a profile, e.g. the resting urethral pressure profile or the stress profile (provided the stress is maintained at a constant level, see below) (Figure 6 A, B). Alternatively the measurement may be made at one or more points along the urethra over a period of time during which conditions may be changing; the results may be presented in the form of a continuous trace, e.g. continuous urethrocystometry, or as a profile, e.g. the micturitional pressure profile.

If the lumen of the urethra is filled with fluid, the intraluminal urethral pressure is a true fluid pressure that is in equilibrium with the pressure exerted by the urethral walls [115]. In practice, however, urethral pressures are usually determined during the filling or storage phases of the micturition cycle, when the urethra is empty and collapsed; as a consequence difficulties arise in understanding, defining, and quantifying exactly what is being measured.

1. Technical aspects

Urethral pressures may be measured by perfusion techniques, by catheter-mounted microtransducers, or by catheter-mounted balloons connected to an external transducer. All 3 methods have advantages and disadvantages. One problem is that, for any technique that uses sideholes or a side-mounted transducer, the measured "pressure" is liable to show an artifactual dependence on the orientation of the sidehole(s) or transducer. This behavior depends on the stiffness of the catheter and may lead to gross artifacts. It can be minimized by choosing a very flexible catheter or a catheter with multiple sideholes or sensors.

a) Resting urethral pressure profile

In perfusion profilometry, catheters between 4 and 10 French gauge appear to give satisfactory results [116]; dimensions significantly greater than this may overestimate urethral pressure because of limited urethral dis-

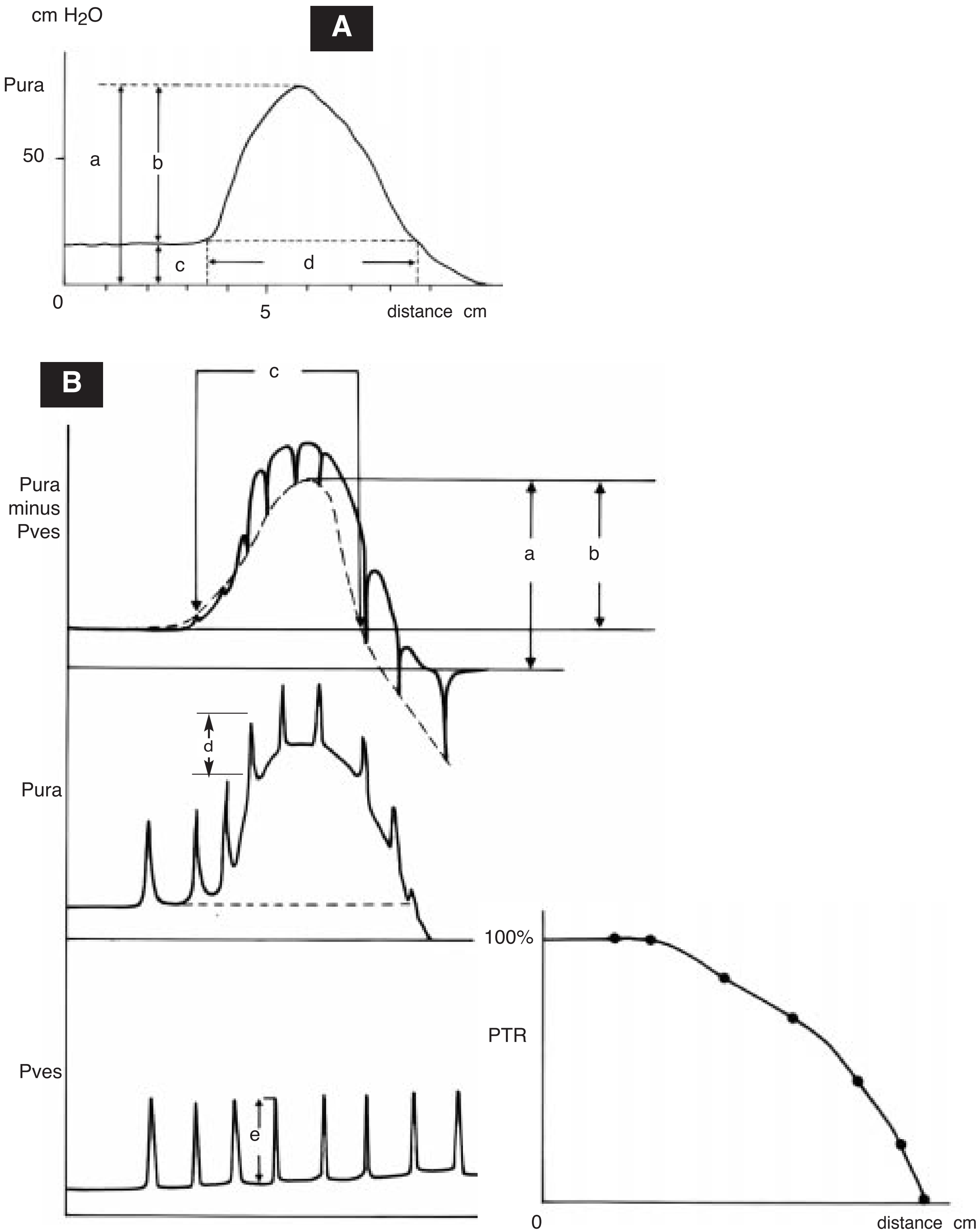


Figure 6 A : Diagram of a female resting urethral pressure profile indicating maximum urethral pressure (a), maximum urethral closure pressure (b), intravesical pressure (c), and functional profile length (d).
6B: Diagram of a female stress urethral pressure profile indicating maximum urethral pressure (stress) (a), maximum urethral closure pressure (stress) (b), and functional profile length (stress) (c). Pressure transmission ratio (PTR) is calculated as d/e.

tensibility [24, 117]. The number and location of side holes should be specified; 2 opposed holes 5 cm from the tip appear to be satisfactory, given the other limitations of the technique[24]. Orientation dependence is not usually important because the catheter is flexible, and most systems use multiple sideholes.

Perfusion is best achieved by syringe driver and not a peristaltic pump. Rates of about 1-2 ml/min can give an accurate measurement of urethral pressure [24], although higher rates may have advantages.

Liquid perfusion systems have been shown to be capable of recording a maximum rate of change of pressure of between 34 and 50 cm H_2O/s, [24] depending on the rate of perfusion, and the compliance of the perfusion system. The catheter may be withdrawn incrementally or continuously; the latter is preferred, and a mechanical or electrical device should be used. The optimal withdrawal speed is less than 7 mm/s [24, 118, 119]; typically, between 1 and 5 mm/s is chosen. Perfusion rate and withdrawal rate are important parameters which interact to determine the response time and spatial resolution of the recording. They have to be carefully chosen with this in mind.

With microtransducer systems there is little smoothing effect, and the high frequency response, estimated at over 2000 Hz [120] is more than adequate to record any physiological event in the lower urinary tract. The method is however prone to several potential methodological artifacts.

The profiles show a significant degree of directional (orientation) dependence [121 - 123]. Resting urethral pressure profiles recorded with the transducer face oriented anteriorly (towards the pubic symphysis) show significantly higher maximum urethral closure pressure and shorter functional urethral length than in other orientations [124]; pressure transmission ratios measured from stress profiles are significantly higher than in other orientations. Most authors have suggested profile recording with the transducer directed laterally within the urethra. It should be emphasised however that this orientation dependence is an artefact related to the presence of the catheter. Fibre-optic microtransducers have been found to show less orientation dependence but greater variability with time than conventional microtransducers [125]; they also record significantly lower pressures [125, 126] and hence may make the diagnosis of intrinsic sphincter deficiency (see below) even more problematic [126].

Balloon systems avoid any orientational dependence, but in the past it has been difficult to make the balloon small enough (a) to provide good spatial resolution along the axis of the urethra and (b) to avoid dilating the urethra so much that the urethral pressure is overestimated. However, it is possible to overcome these problems.

Urethral pressure varies with bladder volume. In continent women urethral closure pressure tends to increase with increasing volume, whereas in stress incontinent women it tends to decrease with increasing volume[127, 128]. Urethral pressure also varies with position. In continent women urethral closure pressure usually increases on assuming the erect position, whereas in stress incontinent women there is either no change or a decrease in pressure on standing [127, 129, 130].

Normal values are difficult to define. There is a dependence on age, which is discussed in section C.II.3 below.

In clinical practice the maximum value of the urethral closure pressure (MUCP), determined from the urethral pressure profile, has a standard deviation of approximately 5 cm H_2O (95% confidence limits ± 10 cm H_2O) [24, 118] or ± 5% [131]. The microtransducer technique has been shown to have greater repeatability and reproducibility [118, 121, 132] the standard deviation of measurements made on a single occasion is approximately 3 cm H_2O (4%) and for measurements on two separate occasions it is 3.5-5 cm H_2O (depending on time separation and menstrual status) [118, 132].

b) Stress urethral pressure profiles

In the measurement of stress urethral pressure profiles the 'stress' may be provided by either repeated coughs or Valsalva manoeuvres on the part of the patient. In the latter case, asking the patient to blow into a manometer to maintain a constant level [133] can control the degree of abdominal pressure rise. The amplitude of abdominal pressure rise during coughing is more difficult to standardise. It is not clear whether the pressure transmission ratio [1] (defined in the following subsection), whilst in itself inherently variable, is dependent [134] or independent [135] of the extent of the rise in abdominal pressure. It has been shown however that the consistency of measurements is significantly greater during the 'cough profile' than the 'strain profile' [136] The most possible flexible catheter is recommended for stress testing to prevent catheter movement and to minimise orientation artifacts.

Stress profile variables show greater variability; within-subjects standard deviations for stress MUCP and pressure transmission ratios have been reported to be 20-25% and 15-20% respectively [136, 137].

2. Description of study results

Study conditions that must be defined when urethral pressure is measured are patient position, bladder volume, rate of infusion and rate of catheter withdrawal. Descriptions especially relevant to urethral pressure measurement include functional urethral length, maximum urethral pressure, and maximum urethral closure pressure. For a stress profile, the pressure transmission ratio (PTR), defined as the ratio of increase in urethral pressure to the increase in intravesical pressure (see figure *6a*), the maximum PTR, and the pressure transmission profile are important factors. Pressure transmission ratios can be recorded at any position along the urethra; the position of the pressure sensor should be stated, e.g. in terms of quartiles of the functional urethra length or in mm from the bladder neck. For continuous measurement of urethral pressure the intrinsic variation in maximum urethral pressure should be recorded.

3. Interpretation of abnormalities

a) Urethral incompetence

Studies have consistently shown that the resting maximum urethral closure pressure falls with increasing age in both men [138] and women, and is lower in groups of stress incontinent women than in continent women; the severity of symptoms is inversely correlated with urethral pressure[113], [121], [130], [139 - 141]. However, significant overlap between the values found in continent and stress-incontinent women limits the discriminatory power of resting profile variables.

Most agree that the variables of the stress urethral pressure profile are of greater diagnostic value than those of the resting profile. Pressure transmission ratio [138], [142], maximum urethral closure pressure on stress, and profile area on stress [143], [144] have each been found to be the most reliable single variable by different authors, although the sensitivity even with these remains poor. Even on the basis of a discriminant analysis using a combined function of 30 resting and stress profile variables, a correct classification was possible in only 78% of patients, suggesting that the urethral pressure profile at rest and on stress is not an accurate test for the diagnosis of urodynamic stress incontinence [145].

b) Urethral pressure variations and urethral instability

During continuous urethrocystometry most patients show fluctuations in maximum urethral closure pressure of variable degree. Numerous authors have suggested that variations in excess of 10 [25], 15 [93], [146], [147], 20 [148], or 25cmH_2O [149] might be looked on as indicating abnormality. Such pressure variations are however commonly seen in asymptomatic women [150], and it has therefore been suggested that variation in urethral pressure might more appropriately be looked on in relative terms, as a proportion of the maximum urethral pressure [119]. Several authors have suggested that variations in excess of 30-33% of the MUCP might be looked on as abnormal [149], [151], [152]. Although such variations have been reported to be associated with an increased likelihood of lower urinary tract symptoms, their clinical significance remains in some doubt[150], [153].

'Unstable urethra' is an involuntary fall in urethral pressure in the absence of detrusor activity [154]. If sufficiently pronounced it may lead to zero maximum urethral closure pressure and allow leakage of urine. It is thus distinguished from detrusor overactivity and from incompetence of the urethral sphincter against increased abdominal pressure. In the collated and revised ICS report [1] it is suggested that "terms such as 'the unstable urethra' await further data and precise definition". The authors of this chapter suggest that the term 'unstable urethra' be used only where a zero or negative closure pressure results from involuntary urethral relaxation. The term 'urethral pressure variation' should be used for lesser degrees of pressure variation, where a positive urethral closure pressure is maintained. The former would seem to be a well documented but uncommon cause of incontinence [136], [155]; the latter is undoubtedly much more common, but of doubtful significance.

4. Indications in incontinent patients

Urethral pressure measurement has been advocated in several conditions in the investigation and management of incontinent patients, especially those suspected of urethral dysfunction, although in few of these situations has its role been unequivocally established.

5. Good urodynamic practice

Good urodynamic practice must be based on an understanding of the limitations of whatever method is chosen, and the precautions required to overcome them.

If a microtransducer is used to record urethral pressure, care should be taken to use the most flexible catheter available. There should be a means of checking the orientation when the catheter is in the patient's urethra.

The orientational dependence (e.g., the differences between maximum urethral "pressures" measured with the transducer facing anteriorly, posteriorly and laterally) should be measured in typical patients, so as to establish how carefully the catheter has to be oriented in routine practice.

If a perfusion method is used, the rate of rise of pressure when the sidehole is completely blocked should be determined, and reported. This is the maximum rate of increase of urethral pressure (in cm H_2O/s) that can be measured, and it determines the response to rising pressures. A cough can result in a rate of increase of 250-

500 cm H_2O/s. To measure a "stress profile" the maximum measurable rate of pressure increase should be at least as large as this (a criterion that may be difficult to satisfy). Division of the maximum measurable rate of pressure increase by the speed of catheter withdrawal (in mm/s) yields the maximum urethral pressure gradient (in cm H_2O/mm) that can be measured. In a normal urethra the urethral pressure gradient may be as large as 5-10 cm H_2O/mm. If the system cannot measure such a gradient, the urethral pressure profile is truncated and the peak pressure is not recorded. The remedy is to increase the rate of perfusion, decrease the speed of withdrawal, or redesign the measuring system to reduce its compliance.

With a perfusion method, frequently a single channel is used both for perfusion and for measuring urethral pressure. In this case, an extra pressure, needed to drive the perfusate through the channel, is added to the measured pressure, which therefore exceeds the urethral pressure. The extra pressure may be allowed for by first measuring the apparent bladder pressure *with the perfusion running*, and then comparing urethral pressures to this artificially elevated baseline value. This method works reasonably well provided that the rate of perfusion remains constant. To minimize the problem, the perfusion channel through the catheter may be made wider (but this makes the catheter stiffer and may produce an orientation artifact); or the rate of perfusion may be decreased (but this will increase the response time and reduce the maximum measurable pressure gradient). Another solution is to use separate channels for perfusion and pressure measurement, which only come together at the sidehole; however, this may increase the stiffness and the expense of the catheter.

If a balloon is used, it should be only slightly greater in diameter than the catheter itself, and not more than 1-2 mm long. It must not be fully inflated, since inflation of the balloon requires an extra pressure over and above the urethral pressure: the balloon should appear half empty. The optimum amount of fluid (gas or air) in the balloon — sufficient to make measurements, but not enough to overinflate it — has to be determined beforehand, and meticulously adhered to.

It is often recommended that intravesical pressure should be recorded continuously throughout measurement of the urethral pressure profile. Unfortunately this requires another measuring channel; the increased catheter stiffness may cause an orientation artifact.

6. Predictive value

Several studies have shown that patients undergoing *unsuccessful* surgery for urodynamic stress incontinence by several different procedures have lower pre-operative resting MUCP and functional urethral length (FUL) than those treated successfully [156 - 162]. In patients treated by colposuspension, those with a pre-operative resting MUCP less than 20 cmH_2O were 3 to 4 times more likely to have an unsuccessful outcome than those with higher values [163] [164]. Two recent comparative studies however, one retrospective case series [165], and one prospective randomised study [166], have shown no difference in outcome between colposuspension and sling in patients with low pre-operative maximum urethral closure pressure. Thus, whether a low maximum urethral closure pressure, suggesting intrinsic sphincter deficiency, is in fact predictive of a poorer outcome of surgery awaits further clarification.

7. Summary

- The resting urethral pressure can be recorded by a number of standard techniques. All involve some degree of approximation.
- The results of both resting and stress urethral pressure measurements are highly influenced by methodological and biological factors.
- Because of the significant overlap of measured variables between different groups of patients, the diagnostic value of these variables is limited.
- Measurements of urethral pressure may have a role in the identification of intrinsic sphincter deficiency (see Section II.9).

8. Future study areas

- Development of new or improved methods of assessing urethral closure
- Developments in transducer design; especially the incorporation of sensors into finer, more flexible catheters
- Clearer definition of profile variables, especially with respect to pressure variation and correlation between these variables and other outcome measures.
- Relationship between urethral pressure variation / urethral instability and detrusor overactivity.

III. LEAK POINT PRESSURE MEASUREMENT

The bladder pressure (p_{det} or p_{ves}) at which involuntary expulsion of urine from the urethral meatus is observed is the leak point pressure (LPP). The rise in bladder pressure causing leakage may originate either from the detrusor (caused e.g. by filling a low compliant bladder or by detrusor contractions) or from an increase in abdominal pressure. Thus there are two different LPP's

— the detrusor leak point pressure and the abdominal leak point pressure — and each is a direct measure of the closure function of the entire bladder outlet under different circumstances.

The detrusor leak point pressure (DLPP) is the value of the detrusor pressure at which leakage occurs in the absence of an abdominal pressure rise. Detrusor leak point pressure measurement was introduced in myelodysplastic children as an indicator of the risk of upper urinary tract deterioration [102]. In these patients and others with neurogenic lower urinary tract dysfunction the detrusor leak point pressure [15, 102, 167, 168]is important [15, 102, 167, 169 - 171] [168, 172, 173] because a high value is correlated with a higher risk of upper urinary tract pathology [102],167, 170, 171] 168], 172, 173].

In contrast, the intravesical pressure at leakage during abdominal stress in the absence of a detrusor contraction is called the abdominal leak point pressure (ALPP). The abdominal pressure increase during the test is obtained voluntarily by coughing (CLPP) or Valsalva (VLPP) [174 - 178] [46, 179 - 182] [183 - 186] [18, 168] 187 - 189] [48] 190 - 192]. Although higher abdominal pressures are reached on coughing [15, 170, 171, 174 - 177] [18, 168, 176, 179, 191, 193], the Valsalva leak point pressure (VLPP) is better controlled and less variable over time [15, 139, 178, 179, 182, 193] [46], 183 - 187] [18, 168, 188 - 190, 192]. CLPP then is used for assessing leakage in patients who fail to leak on VLPP. The abdominal leak point pressure is a diagnostic tool in patients with stress incontinence (Figure 7).

1. Technical aspects

The leak point pressure is measured by marking on the pressure recording the moment at which urine is expelled from the urethral meatus. This observation can be made by fluoroscopy [48] 102, 167, 170, 190], direct visualisation [15, 139, 174 - 176, 193] 180], 181, 184 - 187] [18, 188, 189, 191] or electric conductance measurements [194 - 197].

The leak point pressure depends on the calibre of the transurethral catheter [15, 168, 194], 198 - 200] and possibly on the method and rate of infusion [168, 198]. DLPP measurements must be made intravesically, but for ALPP measurements rectal or vaginal pressure measurement appears feasible [15, 18, 19, 194]. However, rectal or vaginal pressure measurements are inherently less reliable than intravesical measurements, and one group reported vaginal Valsalva leak point pressures to be significantly lower than those measured concurrently in the bladder [15]. Most authors now accept that the presence of a urethral catheter produces artificially high abdominal leak point pressures, and thus favour vaginal or, mostly, rectal abdominal pressure recording. This of course has the consequence that *the absence of detrusor activity and low compliance during the test* has to be documented in a different way [46], [168], and that the quality of the rectal or abdominal pressure measurement tends to be uncertain because it cannot be checked by a cough test.

Besides the influence of the catheter, VLPP is also dependent on bladder volume [15] 183 - 186] [18, 168, 188] 190, 201], and may be influenced by pelvic muscle contraction or urethral distortion during straining. During the test the bladder should be adequately filled: about half the cystometric capacity (200~300 ml in adults) is suggested [183, 185, 188, 194, 202] 168, 190, 191, 197]. With proper precautions the VLPP is a reasonably reproducible measurement [15, 168, 194, 197, 203]. The position of the patient at the time of measurement should be noted.

The contribution of the resting intravesical pressure to the abdominal leak point pressure is controversial. The increase in intravesical pressure from its resting level in the empty bladder was proposed originally [178]; the value of the intravesical pressure measured from its true zero is sometimes used [102, 167, 174, 177, 193, 179, 184, 186, 187, 198, 200]; the increase in intravesical pressure from its resting level immediately before straining or coughing has also been used [15, 139, 175, 176, 188, 193, 194] (Figure 8). Particularly in the sitting and standing positions, when the resting intravesical pressure may be high, there may be large differences (up to about 50 cm H_2O) between abdominal leak point pressures estimated in these different ways. CLPP is generally higher than VLPP in the same patient (Figure 8) [15], 18, 168, 189, 191].

2. Description of study results

The following study conditions should be specified: the position of patient, the type of leak point pressure assessment, the bladder volume (and its relation to the maximum bladder capacity), the location and type of the pressure sensor, the presence and size of a urethral catheter, and the method for detecting leakage. For the abdominal leak point pressure the method of applying abdominal stress and the baseline from which the pressure is measured (resting with empty bladder, resting immediately before straining or coughing, or true zero of intravesical pressure) should be specified. The results are expressed as the lowest pressure at which leakage is detected. Associated pathology, if present (e.g. cystocele) should be included in the results. It must be kept in mind that the quality of instructions given to the patient may affect the results.

3. Interpretation of abnormalities

a) Detrusor leak point pressure

The primary aim of measuring the detrusor leak point

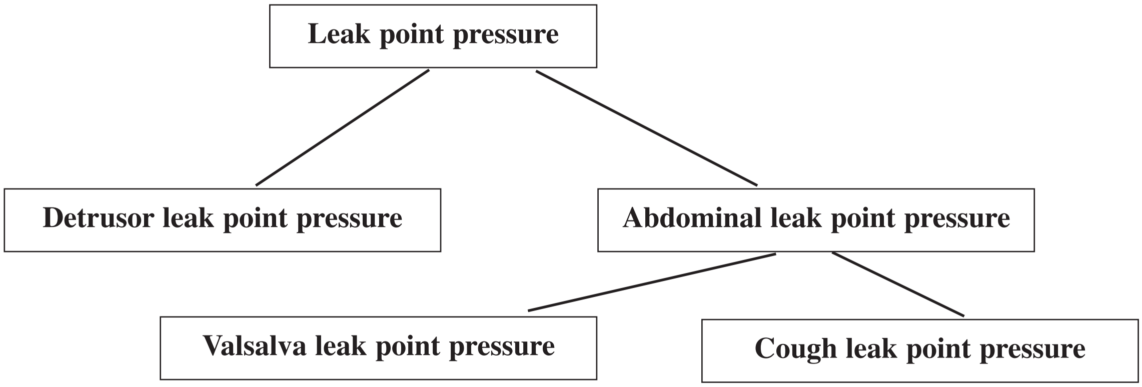


Figure 7 : Nomenclature for leak point pressures

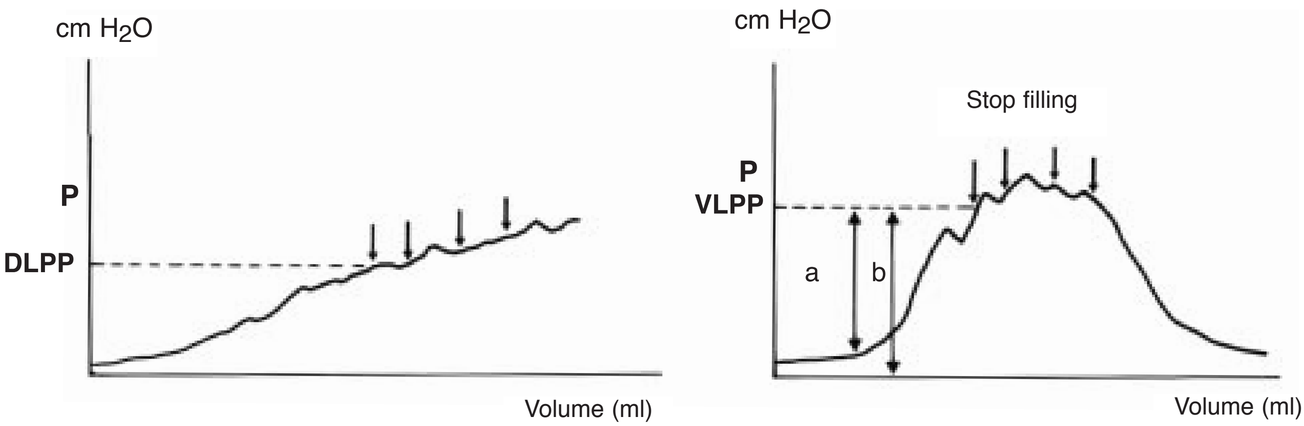


Figure 8 : Measurement of detrusor leak point pressure (DLPP: left) and Valsalva leak point pressure (VLPP: right). The rise in pressure from the base line (a) or from the zero level (b) represents VLPP depending on the investigators. Arrows indicate leakage.

pressure (DLPP) is to assess the risk to the upper urinary tract [168, 182, 183]. The critical cut-off value between high and low leak point pressure is approximately 40 cm H_2O. Patients with neurogenic bladder dysfunction and a DLPP above this level are at risk for upper urinary tract deterioration [102, 168, 172, 173, 183, 199, 177, 204 - 207].

b) Abdominal leak point pressure

The abdominal leak point pressure (ALPP) assesses the abdominal pressure (or pressure increase) that causes stress incontinence and thus offers a direct measure of the urethral contribution to continence [168, 182, 183]. High values (greater than 90-100 cm H_2O) suggest that stress incontinence is associated with descent of the bladder base descent or so called "hypermobility" [168, 185, 188], reflecting pelvic floor weakness. A co-existing cystocele may cause artifactually high leak point pressures and should probably be repositioned during the test [193]. Low values, less than about 60 cm H_2O, reflect more severe stress incontinence and suggest that there is intrinsic sphincter deficiency [168, 178, 183, 185, 188, 189, 202]. Low ALPP is likely to be associated with increased leakage on pad tests [191, 197, 208, 209] and increased symptomatic severity of stress incontinence [46, 48, 167, 168, 184, 202, 210, 211], but some reports contradict this association [59, 63, 212, 213]. There is a low concordance between low maximum urethral (closure) pressure and low ALPP [15, 167, 176, 178, 180, 181, 193] [48, 168, 183, 185, 197, 211, 214 - 216]. Thus, the gold standard method for the diagnosis of intrinsic sphincter deficiency is controversial. The value of the ALPP is related to pelvic floor muscle properties [48, 208]. A recent report has suggested that iatrogenic low ALPP might be caused by simple hysterectomy [217].

4. Indication for LPP measurement in incontinent patients

The detrusor leak point pressure should be assessed in patients with overflow incontinence, particularly of neurogenic origin. In those with neurogenic detrusor overactivity detrusor pressure should be monitored whether they are incontinent or not, particularly if coexistent detrusor-sphincter dyssynergia allows high detrusor pressures to be sustained. It is usually of no interest in those with urge incontinence without serious neuropathy [167].

Abdominal leak point pressure measurements are used frequently to evaluate urethral function in patients with stress incontinence. A tentative diagnosis of intrinsic urethral sphincter deficiency may be made from a variety of tests [218], including X-ray classification and low resting urethral pressure profile values [168], see section II.9. At present however a low abdominal leak point pressure (< 65 cm H_2O) appears to be the most widely accepted method of diagnosis [139, 167, 178, 180, 181, 193, 183 - 189] [203, 214, 218 - 223] [48, 168, 191, 192, 210, 224 - 226].

5. Good urodynamic practice

a) Transurethral catheter

The catheter size must be considered in the assessment of either type of leak point pressure, since a transurethral catheter might significantly increase the pressure reading at leakage, and some patients may not leak at all with such a catheter [168, 169, 191, 194, 197 - 200, 224].

In the case of the detrusor leak point pressure, the effect of the catheter may be increased by the presence of urethral obstruction (for example detrusor-sphincter dyssynergia, non-relaxing urethra, urethral stricture, or prostatic obstruction). If such a catheter artefact is suspected in DLPP measurements (for which intravesical pressure measurement is essential), the "real" DLPP may be approximated by removing the urethral catheter when the leakage occurs, and replacing it immediately when this leakage stops [199]. The pressure value at this last moment may be a better estimate for the DLPP. An alternative would be to use suprapubic intravesical pressure measurement.

b) Bladder volume and filling rate

• Detrusor leak point pressure

The bladder should usually be filled at a rate that will not cause an artifactually rapid increase of detrusor pressure, since this will reduce the bladder volume at leakage. For patients with neurological pathology this is of particular importance as they may experience decreased compliance or detrusor contractions caused by too fast filling even at filling rates as low as 10-20 ml/min [227].

• Abdominal leak point pressure

When the bladder is filled for ALPP measurements, the test should be undertaken after possible detrusor reactions to the filling have subsided. The volume at which the leakage occurs should also be compared to the functional bladder volume: if the leakage volume is much higher than the regular bladder volume in everyday life, then the measured leak point pressure has little pathological impact [177, 225]. Typically the ALPP is measured at a bladder volume of 200 ml.

- Patient position

For *detrusor leak point pressure* measurement the position of the patient is not expected to have a significant influence. This test is mostly performed in the supine position.

For *abdominal leak point pressure* measurement, the patient position is of marked influence. The test should be performed in the standing position, if possible for the patient, but in any case in the position that will lead to incontinence as judged from the patient history.

- Marking of leakage

Marking the exact moment of leakage is pivotal for this assessment. As leakage is usually detected by visual or X-ray observation, the fast pressure changes that occur during coughing may easily lead to misinterpretation of the actual value of the leak point pressure. Electrical conductance recording appears to be the best method of detecting the moment of leakage, but its complexity is a drawback.

- Patient instructions

The instructions to the patient for ALPP testing (for example straining or coughing with increasing intensity) should be clear, concise, and unequivocal.

- ALPP: Absolute pressure value or increase from baseline?

Many investigators use the increase from the resting pressure (measured either at the beginning of filling or just before straining) as the value of the ALPP. This is contrary to the idea that the ALPP represents the total bladder outlet resistance. In a sitting or standing position, a resting intravesical or abdominal pressure of 20-50 cm H_2O is not uncommon [184], depending on body mass [228]. The ICS recommended use of the absolute intravesical pressure [227]. The consequence is that all reports using the pressure *increase* should be re-evaluated by adding the resting pressure to the ALPP values found (about 20 cm H_2O for sitting and 40 cm H_2O for standing patients, if the actual values are unknown). This of course raises the question of the reliability of the ALPP cut-off values, as the actual data for these values may be derived either from the absolute pressure or from the pressure increase. Fortunately, in clinical practice this difference does not seem of great importance.

6. Predictive value

a) Detrusor leak point pressure

A detrusor leak point pressure > 40 cm H_2O is a definite risk factor for upper tract deterioration [29], [30], [168], [172], [173], [199], [177], [204 - 207] especially if incontinence occurs in everyday life [177]. Early intervention to reduce the pressure in such patients will protect the upper urinary tract [30], [168], [172], [173], [199], [177], [204 - 207].

b) Abdominal leak point pressure

When the diagnosis of intrinsic sphincter deficiency is based on a low ALPP the therapy of choice is a sling procedure, or the injection of bulking agents [168, 202]. The clinical outcome of these therapies for patients with low ALPP is not consistent [46], [216], [223], [229 - 231], [232 - 236], [219], [220], [237 - 239]. In addition, many of these authors demonstrate a post-operative increase in ALPP but not in urethral closure pressure.

7. Summary

- Detrusor leak point pressure measurements are indicated for patients with neuropathic conditions and those who are unable to empty their bladder, because levels above 40 cm H_2O place the individuals at risk for upper urinary tract deterioration.
- Abdominal leak point pressure measurement is a reasonably reliable method to quantify stress incontinence, and a low value is one way of identifying intrinsic sphincter deficiency.

8. Future study areas

- Standardization and improvement of study methods and conditions [240 - 246], including patient position, transurethral catheter, bladder volume, and detection of leakage.
- For detrusor leak point pressure: prospective studies on the development of upper urinary tract changes (not only in neurogenic cases) with elevated DLPP. As it may be unethical to perform these studies on patients, animal models should be used.
- For abdominal leak point pressure: Further standardization of methods and conditions, sharper definition of cut-off values, more evidence for significance of cut-off values for diagnosis and for prediction of outcome.

IV. UROFLOWMETRY AND RESIDUAL URINE MEASUREMENT

Uroflowmetry is a measurement of the rate of flow of urine expelled via the urethra (the external urinary stream) during voiding. It gives an assessment of voiding in a simple, non-invasive, and relatively inexpensive way. Residual volume is the volume in the bladder immediately after voiding is completed.

1. Technical aspects

A closed room where the patient can void in privacy and without interference is preferred whenever possible. Although one study in women was able to demonstrate no difference between pre- and post-instrumentation flow rates [247], uroflowmetry without previous catheterization is desirable. It is important to ensure that the micturition is representative and that an adequate volume is voided. If possible, a voided volume of at least 150 ml, and preferably 200 ml (correspondingly less in children: 50 ml or more) should be obtained. At least two uroflowmetries should be performed when obstruction is suspected, since a single flow can be misleading [248]. Home uroflowmetry by means of different portable devices has been accepted as a more accurate technique because it facilitates multiple measurements [249], [250].

For residual urine measurement in-and-out transurethral catheterization or lower abdominal ultrasonography is usually performed. The investigation must insure that the residual urine is measured accurately and completely, taking into account any urine retained due to vesicoureteral reflux or bladder diverticula. It is also important to make the measurement immediately after voiding. If catheterization is used the catheter should be withdrawn slowly to ensure complete emptying [251]. Transabdominal ultrasound is non-invasive but it requires expensive equipment. Portable ultrasound equipment is cheaper and provides a less accurate assessment, but is sufficient in most cases.

2. Description of study results

The traces and relevant variables should be included in the report of uroflowmetry. Uroflow traces should always be examined to rule out the errors that can occur with automatic reading [252]. The normal flow curve usually has a smooth, near-Gaussian shape, and any spikes of short duration (less than about 2 s) probably represent artifacts, due either to sphincter contraction, abdominal straining or movement of the urine stream in the funnel.

The variables include voided volume, maximum flow rate (Q_{max}), average flow rate (Q_{ave}), voiding time and flow time, which are currently displayed by most uroflowmeters. Q_{max} is the maximum measured value of the flow rate, and Q_{ave} is voided volume divided by voiding time. Flow time is the time over which measurable flow actually occurs.

Since there exists a non-linear relationship between flow rates (Q_{max} and Q_{ave}) and the voided volume, the voided volume and residual urine volume should be stated along with the values of these flow rates. The International Continence Society recommends presenting the results in a simple layout: voided volume/ Q_{max}/ residual volume [1]. Flow time and voiding time can be of interest when interpreting some patterns [253].

3. Interpretation of abnormalities

Normally, the volume of residual urine should be very small. In adults, values up to about 25 ml (measured within a few minutes of voiding) are usually considered within normal limits. Elevated residual urine (about 100 ml or more) warrants careful surveillance and/or treatment, in relation to the other parameters of measurement and the clinical situation. In children, a residual urine volume greater than about 10% of the maximum cystometric bladder capacity may be considered elevated. In the frail elderly, residual urine volumes of about 100 ml are common and may be acceptable, although they may affect choice of treatment for incontinence.

When a normal Q_{max} and a normal voided volume without residual urine are present, in either sex, infravesical obstruction or reduced detrusor contractility is unlikely. However, there is a considerable overlap in flow rates between obstructed and unobstructed patients, in males as well as females [254, 255]. Thus measurement of the flow rate alone has limited value when determining if obstruction is present in a particular patient.

Several different nomograms have been used to interpret the measured flow rates. Siroky's nomogram is used for males and the Liverpool nomograms developed using a large number of subjects have scales for males and females [254, 256]. A peak flow over the 90th percentile on the Liverpool nomogram may be suspicious for detrusor instability, but this finding is not uniformly accepted by all investigators. Flow acceleration (defined as the maximum flow divided by time to maximum flow) has also been proposed as a sign of detrusor instability [257]. However, many patients with instability have uroflow values within the normal range. Some initial work has been done on flow rates in school children [258, 259], and there is some discrepancy from adult nomograms that awaits further evaluation.

Low Q_{max} with or without residual urine is a clue to obstruction and/or to reduced detrusor contractility, although flow rate decreases with age [260]. Bladder outlet obstruction in females is rare. However, up to 30% of females with obstruction will have some degree of incontinence, although this will rarely be the only symptom. A plateau-shaped flow curve with a low Q_{max} is also suggestive of obstruction, but only pressure-flow studies can provide an accurate diagnosis. Incontinence can also be a presenting symptom in an obstructed male, due either to overflow incontinence or to detrusor instability secondary to obstruction.

A poor flow rate and elevated residual urine are more commonly due to an inadequate detrusor contraction. Repeated measurements of residual urine are needed to confirm the results [261]. They may be associated with a pronounced cystocele [262]. Residual urine may be overestimated in patients with vesicoureteral reflux, hydroureteral nephrosis, or bladder diverticula. In these conditions, X-ray or ultrasound imaging of the bladder at the completion of voiding will clarify the true post-void residual volume.

4. Indication for uroflowmetry and residual urine determination in incontinent patients

Residual urine should be determined in all patients. Although the probability of an abnormal uroflowmetry in an incontinent patient is low, several conditions that alter the voiding phase can coexist with incontinence. To exclude them, uroflowmetry is advisable for any incontinent patient. Residual urine can be conveniently determined immediately afterward.

5. Good urodynamic practice

- Flowmeter calibration should be checked regularly by following the manufacturer's instructions or, at a minimum, by pouring a known volume of water into the flowmeter at a physiological rate and checking the recorded volume.
- Patients should void with a "comfortably full bladder". Since this may be difficult to arrange, the concept of a flow clinic, where patients may drink fluids and void a number of times, may be considered.
- After voiding, patients should be asked whether the void was representative of their usual pattern
- Flow traces and the computer output derived from them should be carefully scrutinized for artifacts and corrected if necessary.

6. Predictive value

There is some evidence that poor bladder emptying, as shown by an abnormally low flow rate [263] and/or an elevated residual urine [108] may predict voiding difficulty after surgery for stress incontinence. These measurements may be useful for pre-operative counseling of patients.

7. Summary

- Uroflowmetry in privacy with the residual urine measurement should be included in the initial work-up of any incontinent subject.

- Ultrasonography is a simple noninvasive way to assess residual urine.
- Uroflowmetry should be performed prior to any urethral instrumentation.

8. Future study areas

- Development of nomograms that are easy to use and can be adjusted to a given population. (Nomograms are also required for children of various age groups, related to their sex and body size.)
- Definition of standardized flow patterns that may be associated with certain conditions related to incontinence.

V. PRESSURE-FLOW STUDIES OF VOIDING

Pressure-flow studies are concerned with voiding and therefore do not usually address incontinence directly. In a given patient, however, a pressure-flow study may shed light on the etiology of incontinence; or voiding dysfunction may be combined with incontinence; or voiding may be involuntary, so that voiding and incontinence are indistinguishable.

1. Technical aspects

The standardization report of the International Continence Society should be studied for nomenclature but it gives limited guidance about technical aspects of the test [264]. Pressure-flow studies are subject to technical as well as physiological artifacts caused by circumstances of the test. The following points should be emphasized.

The urethral catheters for the study should be 8 French gauge or smaller in size. To ensure accuracy, recording a cough immediately before and after micturition is mandatory, and more importantly, direct inspection of the raw pressure and flow data is essential to enable artifacts and unreliable data to be recognized and eliminated. If the flow pattern in the pressure-flow study is not representative of free-flow studies in the same patient, then the reliability of the interpretation may be questionable.

The stream of voided liquid should flow directly into the flowmeter (not via tubing) and the distance between the external meatus and the flowmeter should be as short as practicable.

2. Description of study results

Since the interpretation of the pressure-flow study depends on pattern recognition, a large number of different variables have been defined to help describe these patterns. Among the important variables are the maximum flow rate Q_{max} and the detrusor pressure at maximum flow ($p_{det.Qmax}$). The voided volume, the volume of post-void residual urine, the presence or absence of abdominal straining, and the flow pattern also provide useful information.

3. Interpretation of abnormalities

As long as technical artifacts have been eliminated, plotting Q_{max} and $p_{det.Qmax}$ on a nomogram provides a simple way to classify the degree of obstruction in males. The ICS obstruction nomogram is one example [264]. A similar nomogram allows the detrusor contraction to be classified in 6 grades as very weak, weak-, weak+, normal-, normal+, or strong [265]. Alternatively, similar classifications can be performed by simple calculations based on the values of Q_{max} and $p_{det.}Q_{max}$ [266]. However, these nomograms or calculations have limitations. They were developed primarily for analysis of voiding in males. They do not take into account any contribution from abdominal straining, nor do they indicate the etiology of any abnormality. The pressure-flow study is not a satisfactory way of estimating the maximum flow rate or the residual urine volume; free uroflowmetry is preferable.

Urethral obstruction may be due to a structural abnormality or to overactivity of the urethral closure mechanism. Structural (anatomic) abnormalities include urethral stricture, posterior urethral valve, meatal stenosis, prostatic enlargement or bladder neck contracture. Overactivity of the urethral closure mechanism may be a voluntary act (e.g., an attempt to inhibit involuntary voiding), or a physiological artifact of the examination, or a learned behavior (dysfunctional voiding) or it may be due to a neurological lesion. These possibilities can be distinguished only with the help of auxiliary information. For example, in a patient with spinal cord injury, obstruction is likely to have a neurological basis and to be due to overactivity of the striated urethral sphincter during voiding (detrusor-sphincter dyssynergia).

• *Obstruction in women*

Recently, a number of authors have attempted to provide a urodynamic definition of obstruction applicable to women. Such a definition would be useful both pre-treatment (as a possible explanation of symptoms), and post-surgery (to establish or rule out iatrogenic obstruction). Groutz et al [267] defined urethral obstruction as a persistently low *free* flow rate of less than 12 ml/s combined with a detrusor pressure at maximum flow greater than 20 cm H_2O during pressure-flow studies. The prevalence was 6.5% among consecutive women patients with various symptoms and etiologies. Lemack & Zimmern [268] examined a population of women with voiding symptoms but not necessarily with obstruction. They suggested that women with voiding detrusor pressure of 21 cm H_2O or more, together with a flow rate 11 ml/s of lower, were obstructed. The prevalence was 20%. Kuo [269] defined bladder outlet obstruction as a voiding detrusor pressure of 50 cm H_2O or greater together with a narrow urethra on voiding cystourethrography. 9.6% of their selected population of women with lower urinary tract symptoms were diagnosed with bladder outlet obstruction. Salvatore et al. [270] defined obstruction as a peak flow rate less than 15 ml/s together with a maximum voiding detrusor pressure greater than 60 cm H_2O. The prevalence in a large group of women with symptoms of urinary tract dysfunction was 1.5%. Blaivas & Groutz [271] developed an obstruction nomogram based on statistical analysis of the maximum detrusor pressure ($p_{det.max}$) during pressure-flow study of voiding, together with the maximum flow rate Q_{max} in repeated *free* uroflow studies. Patient with $p_{det.max}$ greater than 57 cm H_2O were classified as either moderately or severely obstructed. Those with p_{det} below 57 cm H_2O were classified as either mildly obstructed or unobstructed depending on the value of free Q_{max} (Figure 9). Among a group of 600 consecutive women, 6% were mildly, 2% were moderately, and fewer than 1% were severely obstructed.

These definitions use different pressures and different flow rate measurements, but Figure 9 allows an approximate comparison. It shows that there are 2 main schools of thought: some define obstruction by detrusor pressures above about 50-60 cm H_2O; others take obstruction to begin at much lower pressures of about 20 cm H_2O, provided that the flow rate is also low. The Blaivas-Groutz nomogram suggests that the lower pressure cut-off may define mild obstruction, and the higher cut-off may define moderate or severe obstruction. As one would expect, the prevalence tends to be higher in studies defining obstruction by lower cut-off pressures, although of course it depends on the patient population being studied.

Nitti et al [272] defined obstruction qualitatively as radiographic evidence of narrowing in the presence of a sustained detrusor contraction. For obstructed women the mean values of $p_{det.qmax}$ and Q_{max} were 43 cm H_2O and 9 ml/s respectively, corresponding approximately to a point near the upper boundary of the mildly obstructed region. For unobstructed women their values were 20 ml/s and 22 cm H_2O, approximately on the boundary of the unobstructed and mildly obstructed regions in the figure.

To summarize, it appears generally agreed that studies falling in the green region of Figure 9 are unobstructed, and that those falling in the amber or red regions are indeed obstructed. In the pale yellow region there is some disagreement, and this region therefore plays a role similar to that of the equivocal region in the ICS nomogram for male obstruction, outlined in blue in the figure.

There is evidence that in some types of urge incontinence voiding pressures are higher, perhaps even higher than normal [273]. Women with stress incontinence, on the contrary, tend to void at lower detrusor pressures than normal subjects. Karram et al [274] showed that 30 continent women voided at a detrusor pressure of 20 ± 14 cm H_2O (mean ± sd), while 70 women with urodynamic stress incontinence voided at a detrusor pressure of 12 ± 11 cm H_2O. Although the corresponding flow rates were not specified, and although the authors interpreted the detrusor pressure as a measure of contraction strength rather than obstruction, these figures suggest that, as one would expect, at least half of the continent women and most of those with stress incontinence were unobstructed according to Figure 9. Some of the continent women probably had pressure-flow studies in the equivocal region. Methods of assessing detrusor contractility in women have not yet been well defined.

4. Indications for pressure-flow studies in incontinent patients

If the free uroflow is normal with no significant residual urine there is usually no indication for a pressure-flow study. If the free uroflow is abnormal and/or there is elevated residual urine, a pressure-flow study may be performed to distinguish between urethral obstruction and detrusor underactivity (poor detrusor contractility), or to help distinguish between neuropathy and a structural urethral obstruction as the cause of detrusor overactivity and related symptoms. If incontinence surgery is being considered, a pressure-flow study may confirm suspected detrusor underactivity and thus help to warn patients who potentially may encounter post-operative voiding difficulty. However, there is no evidence that pressure-flow studies are more reliable predictors of voiding difficulty than uroflowmetry and residual urine determination [275].

In a study of women with lower urinary tract symptoms, but without a primary complaint of simple stress incontinence or overt neurological disease, pressure-flow studies demonstrated significant abnormalities in 33% [276]. The abnormalities included obstruction from various causes in 15%, dysfunctional voiding in 12%, and detrusor-sphincter dyssynergia as the initial presentation of neurological disease in 4%. Thus pressure-flow studies can provide valuable information in such cases.

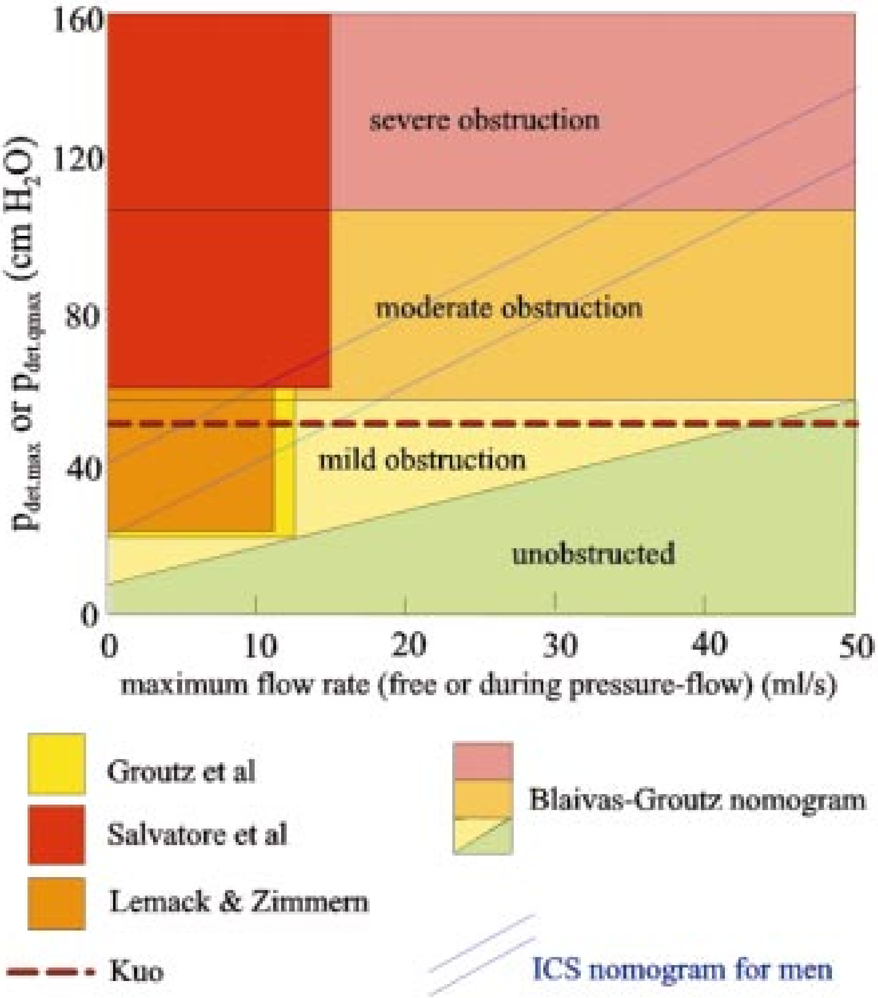


Figure 9 : Figure comparing various urodynamic definitions of obstruction in women. The ICS nomogram for the definition of obstruction (developed for males) is shown for comparison. Note that the pressure and flow rate variables plotted are not identical for all definitions.

5. Good urodynamic practice

- Measurement of pressures requires the same standards and precautions as for filling cystometry.
- Secure taping of catheters is even more important during pressure-flow studies, because the flow tends to expel the urethral catheter.
- Catheter size is especially important because too large a catheter can obstruct the urethra. 8 French gauge is the recommended maximum.

6. Predictive value

The evidence that pressure-flow studies can improve the outcome of incontinence treatment is very limited. Their main function is usually to help recognize or delineate possible neurogenic dysfunction, which would make it unlikely that standard incontinence treatment would be successful, and might rule it out entirely.

a) In women

There is little evidence that pressure-flow studies can predict success of surgery for stress incontinence. In one retrospective review of 50 patients who underwent a rectus fascia suburethral sling procedure, there was a markedly higher risk of objective failure among those who voided pre-operatively with the Valsalva maneuver (54% versus 17%) [277]. There is tentative evidence (requiring confirmation) that women who fail surgery for stress incontinence have lower opening and closing detrusor pressures in pre-operative pressure-flow studies than those in whom the surgery is successful [278]. The role of pre-operative voiding pressure in predicting outcome of surgery requires further clarification.

There is no evidence that pressure-flow studies (as opposed to uroflowmetry) can help to identify subjects with a higher risk of post-operative retention [263] [275] [279].

The evidence that urodynamics can improve outcome for women with possible iatrogenic urethral obstruction after incontinence surgery is unclear. In a retrospective analysis of 51 women who underwent urethrolysis for voiding dysfunction post cystourethropexy, urodynamic variables were not able to predict which of them would benefit [280].

b) In men:

There is limited evidence that frail elderly men with urge incontinence do better after TURP (in particular, that their incontinence improves) if pre-operative pressure-flow study demonstrates clear obstruction [281]

7. Summary

A free uroflowmetry and a determination of post-void residual urine should always precede pressure-flow studies.

Pressure-flow studies are not required in the diagnosis of all types of urinary incontinence.

They may provide an answer to a specific question in situations where neuropathy and/or urethral obstruction are suspected.

8. Future study areas

Further refinement of nomograms for pressure-flow studies in both normal and incontinent women.

Further study of the predictive value of pressure-flow studies in incontinence treatment.

VI. SURFACE ELECTROMYOGRAPHY

Electromyography (EMG) of the urethral sphincter, the anal sphincter, or the pelvic floor is an established method for the diagnosis of lower urinary tract dysfunction [282 - 284]. Two types of information can be obtained from the EMG: (a) a simple indication of muscle behaviour (the kinesiological EMG); (b) an electrical correlate of muscle pathology. If one is looking for specific neuropathological information, a neurophysiological approach, based on an EMG of type (b), as described in chapter 4, is necessary. During urodynamic investigation an EMG of type (a) is usually obtained. The interpretation is mainly restricted to recording of progressively increasing EMG activity during filling of the bladder (guarding reflex), and of timely relaxation of the pelvic floor during voiding [285, 286]. While an EMG of type (b) requires needle or wire electrodes, a kinesiological EMG of type (a) can be obtained by needle electrodes or surface (patch) electrodes [286 - 289]. Although needle electrodes are somewhat less subject to artifacts, surface electrodes are superior for this purpose, because the signal is obtained from a larger volume of muscle and therefore is less subject to fluctuations caused by the normal physiological cycling of motor units. Surface EMG recording of this type, as an indicator of appropriate pelvic floor function or of absence of abdominal straining during voiding, has found a place in rehabilitation or biofeedback training [290 - 297] (e.g. flow-EMG recordings).

1. Technical aspects

The International Continence Society has published technical advice on the use of urodynamic equipment, with suggestions for EMG recording [298]. These suggestions describe methods for recording EMG activity and define the amplifier and signal-processing characteristics.

Patch or surface electrodes are often placed so as to record EMG activity in the anal sphincter because of its relatively easy access. However, this activity is not always correlated with the activity in the striated urethral sphincter [289, 299 - 304]. This is particularly true in patients with neurogenic lower urinary tract dysfunction [301], [302], and in patients who strain to void but relax the urethral sphincter simultaneously. In female patients, vaginal surface electromyography may offer a better approximation for the activity of the striated urethral sphincter [289].

Surface EMG recordings are highly subject to artifacts that cannot be recognised from the EMG trace provided by standard urodynamic equipment. Therefore, the EMG signal should always be monitored throughout the test via an audio or video (oscilloscope) output, to check that it has physiologically plausible characteristics. Patch electrodes in particular are subject to electrical artifacts if liquid runs over them. If this happens during voiding, it can misleadingly suggest detrusor-sphincter dyssynergia.

2. Description of study results

The surface EMG is usually obtained simultaneously with cystometry. Additional descriptive material that should be provided includes the location or type of electrode, the characteristics of the recorder, and the method of monitoring for artifacts. The amplitude of the EMG signal is measured in mV (microvolts), and the scale should be indicated on the tracing. However, the amplitude may be difficult to interpret because it depends on the distance between the electrodes and the muscle.

3. Interpretation of abnormalities

If reduced EMG activity, or none, is found in the sphincter during bladder filling, this may indicate an incompetent urethral closure mechanism [47, 294]. Normally, the EMG should become almost silent (sphincter relaxation) during voluntary voiding. If this is not the case, urethral function may be overactive. Waxing and waning of the sphincter EMG during voiding suggest a functional obstruction (detrusor-sphincter dyssynergia in neurological conditions, dysfunctional voiding in non-neuropathic patients). An increase of EMG during voiding may indicate that there is abdominal straining.

4. Indication for EMG measurement in incontinent patients

When urodynamic studies are performed in an office setting, surface EMG recording can be used to test the ability of the patient to control the pelvic floor area voluntarily and to give a gross indication of possible lack of co-ordination between the detrusor and the pelvic floor (during voiding). As a diagnostic tool, EMG in a normal urodynamic setting is probably most useful for detecting detrusor-sphincter dyssynergia [282 - 284, 286, 287, 290, 305 - 309], although this can also be inferred from fluoroscopic observations [305].

Surface EMG technique is also valuable in judging the effect of pelvic floor training therapy and can be used for biofeedback treatment.

5. Good urodynamic practice

For surface electromyography, the two signal electrodes should be placed as close as possible to the muscle involved, usually the anal sphincter.

A third (ground) electrode, attached if possible over a bony prominence, should be used.

Good mechanical adherence, resulting in good electrical contact with the skin, is vital. Preliminary skin preparation may be necessary.

It is advisable to test different types of electrode until one is found that consistently provides good electrical contact.

It is inadequate to rely only on the EMG trace provided by standard urodynamic equipment. The EMG signal should also be monitored throughout the test via an audio or video (oscilloscope) output.

6. Predictive value

There is no convincing evidence that surface EMG measurement improves the outcome of incontinence treatment.

7. Summary

- Surface electromyography has limited value in the routine urodynamic diagnostic work-up.
- A more accurate neurophysiological approach to measurement and interpretation of the sphincter EMG may be warranted in neuropathic conditions (see chapter 4).
- Therapeutic use of surface EMG may be advised in rehabilitation or biofeedback procedures to improve pelvic floor function.

8. Future study area

Definition of the most appropriate role for surface electromyography (see also chapter 4).

VII. VIDEOURODYNAMICS

Videourodynamics traditionally combines a routine urodynamic study with X-ray or ultrasound imaging [306, 310 - 314], although new imaging techniques such as MRI and nuclear cystometrography are coming into use. Videourodynamics is used for patients with complicated lower urinary tract dysfunction, for example lower urinary tract dysfunction due to a neurological condition [311, 313 - 320]. It also can offer a more accurate diagnosis in other patients [306, 312, 314, 321-323, 324 - 329]. Overall, the invasiveness of the study may adversely affect the functional results obtained by this method of testing; therefore, it should not be considered a first line evaluation.

Most of the advantages of videourodynamics stem from simultaneous measurement of pressure and visualization of the anatomy. Incompetent bladder neck or inadequate urethral closure during filling, or the location of urethral obstruction during voiding, can be documented directly. Descent of the bladder base, bladder base hypermobility and intrinsic sphincter deficiency can be readily distinguished. Incontinence (leakage of contrast medium) can be demonstrated fluoroscopically.

Dyssynergia between detrusor and external sphincter or bladder neck can be documented. Moreover, videourodynamics has the advantage that any sign of reflux during the filling or voiding phases can be detected immediately, and that bladder diverticula or other anatomical malformations can be documented. The disadvantages of videourodynamics are radiation exposure, high initial and running costs and less comfortable conditions for the patient.

Ultrasound videourodynamics, although it has the advantage of no exposure to radiation, requires direct contact of the ultrasound transducer with the patient's body in the area of the lower urinary tract. Large probes placed intravaginally or intrarectally may change the anatomical conditions in this area. Other disadvantages include inability to observe the upper urinary tract synchronously or to visualise the whole urethra, including the region of the striated urethral sphincter, especially in men.

1. Technical aspects

Videourodynamic investigation takes place under fluoroscopy if X-rays are used (Figure 10). It should always

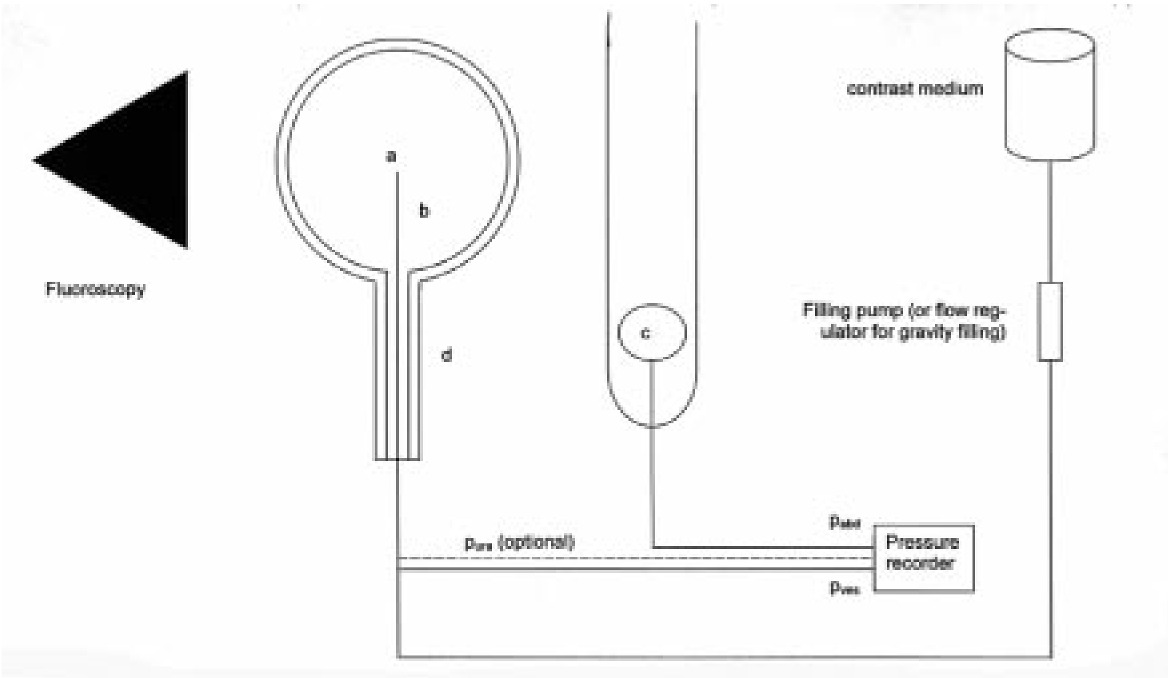


Figure 10 : Schema of videourodynamic equipment. A double lumen intravesical catheter allows bladder filling (a) and simultaneous pressure measurement of pves (b). The rectal pressure is measured for pabd (c). Optionally a triple lumen intravesical catheter will also allow simultaneous measurement of pura (d).

begin with an image taken before any contrast has been introduced. In many cases a plain film can be taken. The bladder is filled with contrast medium, which means that the flowmeter, and possibly the transducer measuring infused volume, should be adjusted to the increased density of fluid. It is of great help, when interpreting the data, if the timing of the video recording is marked on the urodynamic tracings. With modern urodynamic equipment, selected video images can be printed as part of the urodynamic recordings. If videourodynamics is not available, cystourethrograms at rest, on straining or coughing and during voiding are of potential value.

The technical aspects basically conform to regular cystometry. Videourodynamics is even more sensitive to artifacts, in particular because of its interference with lower urinary tract function (e.g. by use of a contrast medium with its higher viscosity or the difficulty of voiding under fluoroscopic monitoring) or because of potential influence on lower urinary tract anatomy (e.g. by an ultrasound transducer).

2. Description of study results

During the filling phase fluoroscopic imaging at regular intervals is necessary. Coughing and/or abdominal straining (see leak point pressure, below) should be recorded to check for descent of the bladder base, hypermobility and/or leakage. During the voiding phase, the start of voiding, the phase of maximum pressure and flow, and the end of the voiding should be documented in the video. After voiding is completed the residual urine should be recorded. Anatomical abnormalities of the bladder contour, urethra, and vesicoureteral reflux can be observed and should be documented. Reflux can occur continuously from the start of filling, at a distinct volume or pressure, during a detrusor contraction, or only during voiding. In all other respects the description of videourodynamic results is similar to that for cystometry.

3. Interpretation of abnormalities

Normally, the bladder should fill without any abnormal appearance to its contour. The normal bladder, when filled to a reasonable volume, has a smooth, more or less spherical shape. The bladder neck should be closed throughout filling and the bladder base should be approximately level with the upper border of the symphysis pubis. During coughing or abdominal straining the bladder base should remain at this level without significant movement inferiorly, the bladder neck and proximal urethra should remain closed, and there should be no observable leakage.

During voiding the bladder neck opens smoothly and widely (but with no ballooning). If it is closed during a voiding detrusor contraction, detrusor-bladder neck dyssynergia may be present. The urethra should be closed during filling and form a smooth conduit during voiding. The external urethral sphincter is open with no intermittent or sustained narrowing during voiding without proximal ballooning. If this is not the case, detrusor-sphincter dyssynergia is possible.

4. Indication for videourodynamics in incontinent patients.

In patients with neurogenic lower urinary tract dysfunction and incontinence, videourodynamics may be useful to define the cause of the incontinence. For incontinent patients with other pathology, videourodynamics is considered when the history and simpler urodynamic tests do not lead to a definite diagnosis or after failure of initial therapy based on less complicated methods of diagnosis.

5. Good urodynamic practice

Videourodynamic investigation requires the same standards and precautions as filling cystometry and pressure-flow studies. Standard radiological precautions and procedures should be followed to optimize image quality and minimize the exposure of patient and staff to radiation.

6. Predictive value

There is some evidence for clinical utility in myelodysplasia [330,331].

7. Summary

- Videourodynamics with fluoroscopy is indicated when the diagnosis remains unclear after simpler tests are performed orwhen complicated pathology is expected from the history and symptoms.
- It has certain disadvantages; the patient is exposed to extra radiation and the technique may influence the lower urinary tract function and/or anatomy.

8. Future study area

Refinements in ultrasound imaging, and other techniques such as MRI and nuclear cystometrography, to enhance their application in videourodynamics.

VIII. AMBULATORY URODYNAMIC MONITORING

Ambulatory urodynamic monitoring (AUM) is the monitoring of leakage, flow recordings and pressure in the bladder and abdomen (rectum or vagina) with or without pressure in the urethra in an ambulatory setting [332 - 335]. It permits monitoring in situations where the patient usually leaks, unattended by medical staff and laboratory equipment. Detection of leakage during the recording is necessary and helps to separate clinically relevant events from artifacts [335]. If the urethral pressure is not recorded during AUM, the diagnostic sensitivity for stress incontinence may be low [336] and the diagnosis of an unstable urethra or that of low urethral closure pressure [335] is less feasible. Recording of flow during micturition enables pressure to be related to flow rate [377]

1. Technical aspects

To record bladder pressure a catheter may be introduced into the bladder transurethrally or suprapubically. Catheter-mounted microtransducers or fluid-filled catheters are commercially available. It is recommended that the urethral catheter should be 6 French gauge or less, and as soft and flexible as cooked spaghetti to avoid pressure artifacts due to bending. The catheter should be inserted only a short distance into the bladder to avoid any contact between the transducer and the bladder wall that might cause pressure artifacts. Vaginal catheters used for recording abdominal pressure should be soft and the transducer should remain in the middle of the vagina without coming in contact with the cervix. Rectal catheters are usually wrapped in a balloon. Stiff catheters in contact with the cervix and over-inflated rectal catheter balloons may cause pressure artifacts as well.

If urethral pressure is recorded, the transducer should be maintained at the maximum urethral pressure point. This may be achieved by a single stitch to the female urethral opening [335] or taping of the catheter to the vulva, penis or thigh; However, movement artifacts and catheter displacement as well as damage to the catheter, remain a problem [333]. Conduction rings on the urethral catheter outside the maximum urethral pressure point can act as a simple, cheap and sensitive leak detector [335]. The Urilos electronic nappy [338],[339] or a temperature-sensitive device [340],[341] are other methods of detecting leakage.

Recording times from 45 minutes up to 24 hours have been described [335] [342]. Starting with a partially filled bladder may reduce the overall recording time [343]. Transducers should be zeroed to atmospheric pressure and calibrated at a specified positive pressure to ensure valid recordings. Empirically, a sample frequency of around 10 Hz gives clinically adequate pressure recordings of a cough.

2. Description of study results

A portable solid state memory unit should record 2 pressures (p_{ves} and p_{abd}) and optionally the urethral pressure, together with flow and leak signals. A window should display all recorded pressures to permit monitoring of the position of the transducer. Push buttons on the solid state memory unit permit event markings when the patient perceives urgency, leakage and micturition. Drinking and voiding should also be recorded simultaneously in a diary [344].

Signals from the portable solid state memory unit are downloaded to a computer after the recording is complete and urethral closure pressure and detrusor pressure are then calculated. The time scale and signal ranges may be changed while the tracings are evaluated on the display or print-out.

3. Interpretation of abnormalities

Conventional cystometry and AUM often give different study results. In asymptomatic volunteers [345 - 347] as well as in symptomatic patients [339, 348 - 354], an increase in the number of detrusor contractions on AUM has been found, compared to conventional cystometry [355, 356]. With AUM, voiding volumes have been found to be lower [346, 347, 349, 353, 354], voiding pressures significantly greater [345, 346, 354, 357] and the micturition flow rate higher [358] than with conventional urodynamics.

During the filling phase, detrusor contractions without subsequent leakage have been found in 38 to 69% of normal volunteers undergoing AUM [345 - 347]. The significance of detrusor contractions not associated with leakage in asymptomatic patients is unknown. It is probably more valuable to concentrate on the detrusor contractions associated with clinical symptoms. The increased number of contractions observed during AUM may be caused by catheter irritation of the bladder wall. Microtip transducer catheters introduced deeply into the bladder cavity may record artifacts due to contact between the transducer and the bladder wall.

Patients with neuropathic conditions and low compliance during conventional cystometry were not found to have a high end-filling pressure during AUM. Instead a significantly increased frequency of phasic detrusor contractions was observed [350]. Low compliance may thus be an artifact of artificially rapid filling during conventional cystometry.

An index to classify detrusor activity observed during the filling phase of ambulatory monitoring may be useful in patients complaining of mixed incontinence [344].

The detrusor pressure recorded during the voiding phase of ambulatory monitoring is often found to consist of 2 waves, where the second is larger than the first one. The second wave or "after-contraction" may be caused by contact between the collapsed bladder wall and the microtip transducer and thus be an artifact, but it may alternatively be a physiological phenomenon [345]. The vaginal or rectal catheters used for recording the abdominal pressure may record artifacts due to kinking of the catheter in the vagina or to rectal contractions, respectively.

During recording of the urethral pressure, the closure pressure may drop to zero due to displacement of the urethral transducer out of the maximum urethral pressure zone. When no leakage is seen simultaneously with a zero closure pressure, displacement of the transducer must be presumed. A decrease in the vaginal pressure recording will cause a corresponding increase in detrusor pressure even though the bladder pressure remains stable. This may be wrongly interpreted as a detrusor contraction.

4. Indications for ambulatory monitoring in incontinent patients

Neurogenic lower urinary tract dysfunction [350], enuresis [359] in older children, evaluation of the effect pharmacotherapy [360] and electrotherapy [361], or failure of previous treatment are other possible indications for AUM.

5. Good urodynamic practice

Signals should be recorded as recommended in the ICS recommendations on ambulatory monitoring [362]. There are a number of cautions that are especially important in AUM. Stringent checks on signal quality should be incorporated in the measurement protocol. At the start of monitoring, these should include testing of recorded pressures on-line by coughing and abdominal straining in the supine, sitting and erect positions. The investigator must be convinced that signal quality is adequate before proceeding with the ambulatory phase of the investigation. Before termination of the investigation and at regular intervals during monitoring, similar checks of signal quality such as cough tests should be carried out. Such tests will serve as a useful retrospective quality check during the interpretation of traces.

The following considerations must be taken into account when using microtip transducers. They will record direct contact with solid material (the wall of a viscus or faecal material) as a change in pressure. The use of multiple transducers may eliminate this source of artefact. The transducers should be calibrated before every investigation. The zeroing to atmosphere, the difficulties with the pressure reference level, and the possibility of a negative detrusor pressure are all just as relevant as in regular cystometry (see section II.2.e, *Pressure measurement*).

Because of these difficulties, the recording of urethral pressure is usually a qualitative measurement with emphasis on changes in pressure rather than absolute values. The use of urethral electrical conductance to identify leakage in association with pressure monitoring facilitates interpretation of urethral pressure traces. Precise positioning and secure fixation of the catheters are essential to maintain signal quality. The orientation of the transducer should be documented.

6. Predictive value

The predictive value of ambulatory urodynamic studies has not been well documented.

7. Summary

- Ambulatory urodynamic monitoring is most commonly used as a second line test, especially when a conventional urodynamic investigation has failed to produce or explain the symptoms.
- It is a sensitive (but not very specific) way of detecting urine leakage, and may be indicated for patients with mixed incontinence symptoms, or those complaining of incontinence without objective evidence of leakage.
- Artifacts associated with catheter displacement may make interpretation difficult.
- A means of detecting leakage is advisable..

8. Future study areas

- Further study of the place and advantages of ambulatory monitoring
- Reproducibility of results in normal and abnormal subjects
- Clinical significance of non-symptomatic detrusor contractions and variables such as contraction number, frequency and amplitude
- Development of a mechanism for catheter fixation
- Improved quality control of recordings
- Development of automatic trace analysis related to leakage episodes

IX. INTRINSIC SPHINCTER DEFICIENCY

1. Background

Stress incontinence is believed to result from two different anomalies: (a) hypermobility of the bladder base and pelvic floor; (b) intrinsic deficiency of the urethral sphincter itself (intrinsic sphincter deficiency, ISD). The urethral pressure profile, the abdominal leak point pressure, and videourodynamics may all be used to determine the competence of the urethral closure mechanism and, if it is incompetent, to distinguish between hypermobility and intrinsic sphincter deficiency. These tests are discussed more fully in sections I.2.1, *Urethral competence and persistent stress incontinence*; II.2, *Urethral pressure measurement*; II.3, *Leak point pressure measurement*; and II.7, *Videourodynamics*.

A diagnosis of intrinsic sphincter deficiency may be based on measurements of the resting urethral pressure profile. A maximum urethral closure pressure of less than 20 - 30 cm H_2O [363] suggests intrinsic sphincter deficiency. On the other hand, a low value of the abdominal leak point pressure (below about 60 cm H_2O) is also accepted as evidence of intrinsic sphincter deficiency (ISD) [178]. Additionally, videourodynamics offers a classification of stress incontinence that covers similar ground [364]. Type I stress incontinence is leakage that occurs during stress with only slight (< 2 cm) descent of the bladder base below the upper border of the symphysis. Type II stress incontinence is leakage on stress accompanied by marked bladder base descent (> 2 cm below the same reference level); the descent may occur during the stress (type IIA) or be permanently present (type IIB). In type III stress incontinence the bladder neck and proximal urethra are already open at rest (with full bladder), with or without descent. Type II clearly corresponds to hypermobility. Types I and III represent different grades of intrinsic sphincter deficiency.

2. Concordance

The videourodynamic classification is based on direct observation of hypermobility. The urethral pressure profile provides a direct measurement of possible ISD at rest but no information about hypermobility. The interpretation of the abdominal leak point pressure in terms of ISD and/or hypermobility seems to be empirical, as there is no obvious reason why a low LPP should correspond to intrinsic sphincter deficiency or a high LPP to hypermobility. Abdominal leak point pressure measurement and urethral pressure measurement both raise difficult issues of standardization, which up to now have not been resolved (see sections II.2 and II.3).

Not surprisingly, these 3 different methods have some correlation but do not always give concordant results (see section I.2.1). ISD and hypermobility may coexist [365]; cough-induced abdominal LPP is not always consistent with urethral closure pressure measurement [197]. Therefore, at present, ISD is not a well-defined concept.

3. Predictive value

In spite of its limitations the concept of intrinsic sphincter deficiency has been used as a guide to treatment. Urethral bulking (e.g. collagen implantation) and suburethral sling operations have been recommended for use in ISD as alternatives to suspension operations that are clearly aimed at correction of hypermobility [218, 366]. However, there is little evidence that the outcome of surgery is in fact improved by patient selection based on assessment of ISD or hypermobility. Urethral bulking seems to work just as well (or as poorly) with hypermobility as without [367] [368]. Burch colposuspension and sling surgery may have similar success rates whether or not there is evidence of ISD [366].

4. Conclusion

Intrinsic sphincter deficiency (ISD) is not a clearly defined concept; different methods of assessing it give different results; it is not clear which method should be preferred. Whenever this term is used it is mandatory to specify the method used to define it, and the standards followed in applying that method.

C. CLINICAL APPLICATION OF URODYNAMIC STUDIES

I. GENERAL

As pointed out in the introduction, urodynamic studies may be performed:

- to determine the mechanism of incontinence and the relative importance of different contributory factors in complex or mixed cases.
- to obtain information about other aspects of upper and lower urinary tract function.
- to predict the outcome of treatment or no treatment, in terms of both success and side-effects, thus allowing appropriate counselling
- to determine the reasons for failure of treatment or to confirm or refute the effects of treatment

The approach to investigation depends on which of these issues is most significant in a specific patient. The approach the clinician adopts for an individual patient will vary depending on:

- the clinical presentation (i.e. type of incontinence)
- the extent of the problem (i.e. the quantity of leakage and its impact on the patient's quality of life)
- the availability of diagnostic equipment and trained personnel to interpret the findings.
- the likelihood that urodynamic investigation will influence decisions regarding treatment
- the predictive value of particular investigations in the specific circumstances presented
- the available treatment options
- the acceptability of those options to the patient
- the risk and cost associated with these investigations

Most clinicians agree that urodynamic studies should be performed in patients with complicated conditions and/or neurogenic disorders, with upper urinary tract dysfunction, or after treatment failures, especially failure of surgery. This argument is not evidence-based. Whenever correct diagnosis of the underlying type of incontinence is important, invasive urodynamic studies are essential. This is especially true in clinical research units.

In contrast, the necessity of urodynamic evaluation in non-neurogenic and uncomplicated incontinence is debatable [369]. In fact randomized trials using patients to be treated with physiotherapy demonstrated no difference in cure or improvement rate whether they had been examined with urodynamics (50 – 59%) or not (57%) [370] [371]. Surgical outcome in incontinent women aged 50 or less was not affected by prior urodynamic evaluation, if they were free of certain adverse symptoms and signs [108]. However, this is a retrospective analysis, and in reality extreme care should be taken to minimize untoward and sometimes irreversible consequences of surgery, as far as they are avoidable by pre-surgical urodynamic assessment.

Other factors which determine strategy include the probability of failure of diagnosis, based solely on signs and symptoms, the cost and invasiveness of the planned treatment, and the reversibility of the planned treatment, in particular the possible consequences of treatment failure. In the following sections, strategies for urodynamic investigation in various populations of incontinent patients will be discussed.

II. ADULTS (MALE)

Males complaining of incontinence will often have additional concerns, especially associated with the presence of benign prostatic enlargement in older men. Thus, joint evaluation of the filling and voiding phases is required for a precise diagnosis. In addition, the length of the urethra, the possibility of obstruction, and the likelihood that incontinence is of the urge type, all make it more difficult to reproduce leakage in males than in females [372]. In the case of previous surgery, evaluation of the urethra by whatever means the physician feels most comfortable (urethrography or urethroscopy) is often done, and a full urodynamic study is mandatory. Urethral or anastomotic stricture and bladder neck contracture are important concerns. Should there be a suspicion of a stricture, a uroflowmetry will provide an accurate assessment of the voiding phase. Preferably this should be followed by an ultrasound determination of the post-void residual urine volume. Strictures can cause great difficulty in passing the urodynamic catheter. In those cases, a urodynamic study using a suprapubic catheter should be considered.

1. Incontinence related to obstruction

A significant percentage of men with obstruction will present with incontinence, which may be related to detrusor overactivity or overflow incontinence. The presence of incontinence by no means rules out obstruction in the male.

There is evidence that men with infravesical obstruction (due either to prostatic enlargement or to urethral stricture) may develop detrusor overactivity and incontinence if no treatment for their obstruction is given [373]. In most men with obstruction, overactivity rather than overflow incontinence will be the mechanism involved in their leakage. In most cases, overactivity will resolve after relief of the obstruction, although this has been reported to be rarer in elderly patients [281]. A substantial number of obstructed patients will have incontinence, and the incontinence has been found to be associated with obstruction but not the residual urine volume in a large survey examining symptoms and urodynamic findings [374]. There is substantial evidence that if only overactivity without obstruction is present, the patient's incontinence can worsen after prostatic surgery [281]. A discussion of the issue may be found in the Proceedings of the 4th International Consultation on BPH. A neurogenic cause should always be sought, since there is a higher rate of incontinence after transurethral resection of the prostate in patients with Parkinson's disease who have poor voluntary sphincter control [375] and in those with clinical features of Parkinsonism who in fact have multiple system atrophy [376]. The latter findings may be suspected if urinary symptoms or erectile failure precede or present with Parkinsonism, and if there is incontinence and a high residual urine [376].

2. Incontinence after surgery

Urinary incontinence may develop in men who have undergone surgery for lower urinary tract problems other than incontinence. A thorough evaluation includes a urodynamic study, and urethrography or urethroscopy. If urodynamic evaluation reveals that there is obstruction as well as incontinence, a combined surgical treatment program can be planned [377].

The term "post-prostatectomy incontinence" is currently used in the literature to describe a wide variety of conditions (Figure 11). There are discrepancies in the reported prevalence of this type of incontinence, since the continence rate is lower when the patients are questioned by an independent observer [378]. Spontaneous recovery within the first year has been reported in a significant percentage of patients [378 - 380], while others advocate prompt evaluation and management [378]. Urodynamic findings are also different depen-

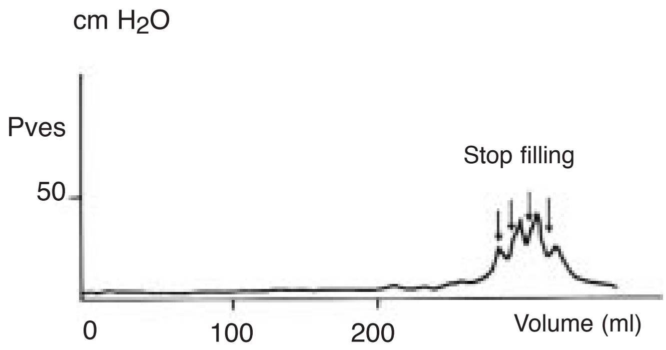


Figure 11 : A 63-year-old man with stress incontinence after a radical prostatectomy. He had a stable bladder, but leaked urine by Valsalva maneuver at pves of 30 cm H_2O or higher. Arrows indicate leakage.

ding on the type of surgery (either transurethral resection of the prostate, open prostatectomy or radical prostatectomy) [138, 379, 380]. Two factors may play a role in bladder dysfunction: 1) asymptomatic detrusor overactivity before surgery [138], and 2) an acute decrease in bladder blood flow after prostatic surgery [381]. However, sphincter incompetence seems to be the most common cause [210]. The mechanism contributing most to incontinence should be identified and managed properly.

The proliferation of techniques for orthotopic neobladder diversion has inevitably resulted in incontinence in the long term survivors, both females and males. Nocturnal incontinence is more frequent, and, as in the previous paragraph, a full urodynamic assessment is mandatory, sometimes with the aid of endoscopy, since all kind of alterations can be found. Storage problems are common and the can be managed by intermittent self catheterization [382, 383].

Post-traumatic incontinence should be examined similarly to incontinence in patients who present with it after lower urinary tract surgery. Detrusor overactivity or low compliance may be present in the filling phase, whereas obstruction or an underactive detrusor can occur in the voiding phase [384] all of these, alone or in combination, can cause incontinence. In these patients, multiple anatomic and neurologic lesions may be present, and a complete evaluation of the bladder and urethra is necessary. Adult enuresis is also frequently associated with "detrusor instability" [385, 386]

III. ADULT (FEMALE)

This section summarises the role of urodynamic studies in commonly encountered clinical problems in the non-neuropathic adult female with urinary incontinence.

1. Stress incontinence (as the only symptom)

In women whose sole or main symptom is stress incontinence, the likelihood of a diagnosis of urodynamic stress incontinence approaches 100% [387, 388], particularly when the physical sign of stress incontinence is also present. Such patients are uncommon in most specialist centers; if a detailed history is taken, they represent only 2 to 10% of referrals. [389] When other symptoms are present, the likelihood of a pure diagnosis of urodynamic stress incontinence may fall to approximately 60% [32, 35]

When non-surgical treatment is being considered the most appropriate strategy would be to rely on clinical assessment. Where surgery is being considered, the role of urodynamic investigation seems to be expanding. The study is aimed not only at the confirmation of urodynamic stress incontinence but also the exclusion of detrusor overactivity and underactivity. It is geared to assessing the voiding pattern, and hence the counselling of patients about the likelihood of post-operative voiding difficulty, and the assessment of sphincter function, which may influence the choice of surgical procedure to be undertaken [390].

A stress test would be the 'gold standard' test for the diagnosis of stress incontinence. The diagnosis of urodynamic stress incontinence should be confirmed urodynamically at cystometry by the absence of involuntary contractions during leakage caused by a stress maneuver. The absence of detrusor overactivity during filling cystometry, however, may not be definitive. It would be important to perform a provocative cystometry; in ambiguous cases, videourodynamics or ambulatory urodynamics should be considered. In patients with previous unsuccessful surgery, or where marked stress incontinence is demonstrated despite limited urethral mobility, the measurement of resting urethral pressure and abdominal leak point pressure may help to identify intrinsic sphincter deficiency [163, 164 390].

2. Urge incontinence

In general, detrusor overactivity is identified during filling cystometry in about 70% of women with complaints suggesting urge incontinence [391], although among those complaining of urge incontinence without stress, the likelihood of observing detrusor overactivity approaches 100% [388].

Therefore, if non-surgical treatment is being considered, the most appropriate strategy is to rely on clinical assessment provided other conditions have been ruled out.. Urodynamic investigation is only appropriate in urge incontinence in the research setting, or when invasive treatments are being considered after failure of drug therapy or behaviour modification techniques. Filling cystometry should allow confirmation of the diagnosis in most cases. When this proves to be inconclusive either because it fails to reproduce the patient's complaints, or fails to provide a pathophysiological explanation for the complaints, ambulatory urodynamics or urethral pressure measurement to search for urethral instability should be considered.

3. Mixed stress and urge incontinence

In patients with mixed symptoms of stress and urge incontinence the likelihood of a diagnosis of urodynamic stress incontinence varies between 30 and 60%, depending on what additional symptoms are present. Initially treatment should be conservative, either directed at the clinical 'best guess' or using combination therapy.

Where conservative treatment fails, urodynamic investigation is appropriate to direct future management (Figure 12). It is important to establish whether stress or urge incontinence is the more frequent complaint, which is the more troublesome to the patient, whether both sphincter weakness and detrusor overactivity are seen on urodynamic investigation, and whether the symptoms and the urodynamic findings correlate with one another. Filling cystometry is the investigation of choice. It should be remembered that in the presence of low urethral resistance, especially in the face of urine leakage during an investigation, detrusor pressures will give an inaccurately low value for detrusor contractility. Repeat cystometry with the bladder neck occluded, e.g. by a Foley balloon catheter, may be a useful adjunct in this situation.

4. Incontinence with symptoms or signs of voiding difficulty

Fewer than 10% of patients presenting with incontinence will complain of symptoms of voiding difficulty, although 25-90% will report such symptoms on direct

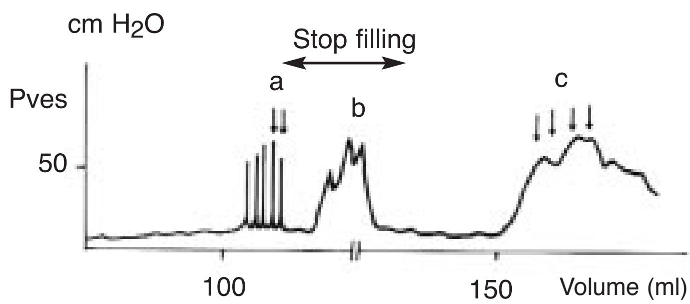


Figure 12 : Motor urge incontinence in a 69-year-old woman combined with stress incontinence. At a bladder volume of 110ml, urinary leakage was caused by sequential coughs (a) but not by Valsalva (b). Involuntary contraction at 160ml resulted in leakage (c). Arrows indicate leakage.

questioning [392, 393]. When there are significant symptoms of voiding difficulty or previous histories of anti-incontinence surgery [394], filling cystometry, uroflowmetry and pressure-flow studies would be appropriate. Since, in women, values of pressure and flow rate indicating obstruction are not clearly defined, videourodynamics may have an additional role in this field (see section II.5.c *Pressure flow studies*). Videourodynamics has no proven advantage in the absence of neurological disease. When there is evidence of increased detrusor pressure, either in the form of impaired bladder compliance during filling, or an obstructive voiding pattern, assessment of the upper urinary tract should also be undertaken.

IV. NEUROGENIC LOWER URINARY TRACT DYSFUNCTION

Neurogenic incontinence may express itself as urge incontinence, reflex incontinence, overflow incontinence or stress incontinence. Not all patients with neurogenic conditions develop typical urinary symptoms or urodynamic findings. For example, urinary symptoms associated with stroke cannot always be assumed to be due to detrusor overactivity, and the site of the lesion does not always provide convincing evidence for the expected urodynamic features. In patients with neurogenic lower urinary tract dysfunction, a specific individual diagnosis of the dysfunction is an absolute prerequisite for a correct choice of therapy [313, 395, 396].

The diagnosis is aimed at describing the (dys)function of the bladder, the urethra and the pelvic floor, their coordination during filling and voiding, and their influence on other pathologic conditions (e.g. autonomic dysreflexia); thus it always requires urodynamic investigation (Figure 13). Because many patients with this condition also show anatomical abnormalities involving the lower urinary tract and dyssynergia that can be demonstrated most easily by imaging, videourodynamics is the urodynamic test of choice [305, 313, 315, 395, 396]. Detrusor-sphincter dyssynergia or detrusor-bladder neck dyssynergia are the main neurogenic dysfunctions in the urethra. The first condition may be diagnosed by sphincter EMG recording, but it appears that videourodynamics is an equally accurate a diagnostic tool for this condition [305] Detrusor-bladder neck dyssynergia can be diagnosed only by videourodynamics [397] Ambulatory urodynamics might offer a better approach to recording the actual lower urinary tract dysfunction under normal circumstances. The ice water test [398 - 400] is believed to be specific for neurogenic detrusor dysfunction, but it must be used judiciously in young children [401]

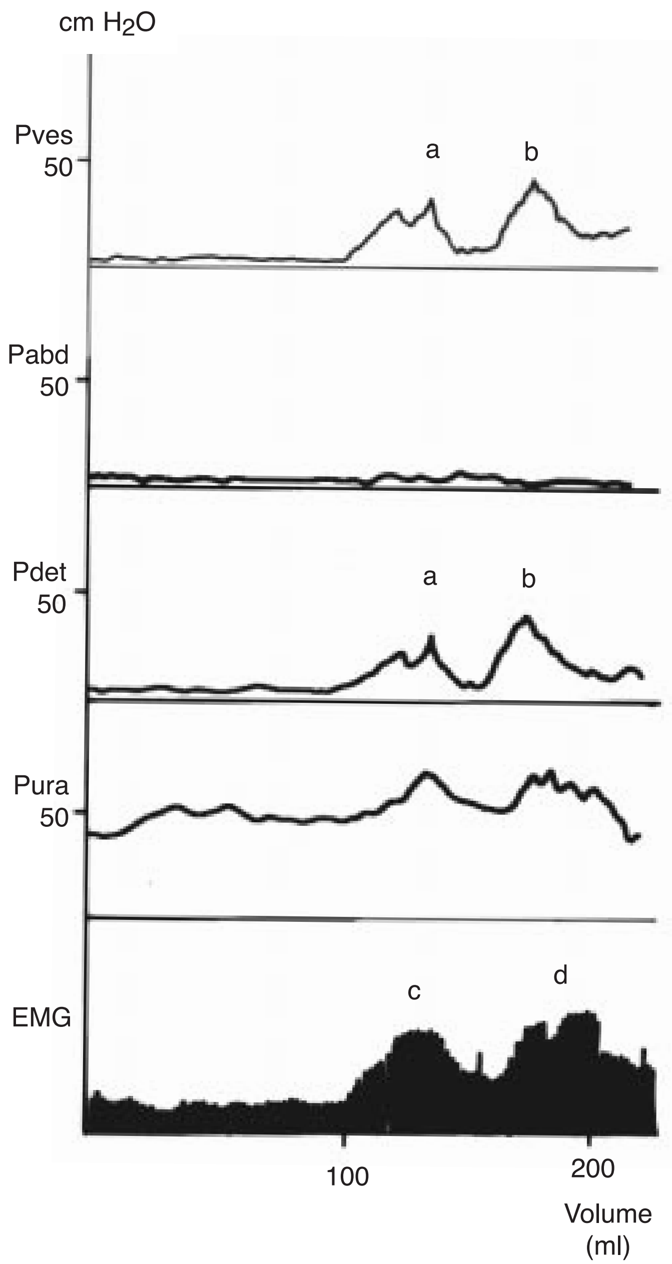


Figure 13 : Urge incontinence and interrupted voiding in a 50-year-old man with multiple sclerosis. High pressure involuntary contractions (a, b) and detrusor sphincter dyssynergia with increased surface EMG activity (c, d) were recorded. Anatomical deformity of the bladder might be present.

A comprehensive classification of neurogenic lower urinary tract dysfunction was adapted by H. Burgdörfer from the literature [402]. The neurological lesion has an immediate impact on the type of dysfunction and predicts incontinence, detrusor function, sphincteric function, and residual urine [402].

Therapy for neurogenic lower urinary tract dysfunction aims to achieve the most nearly physiological filling and voiding condition [313, 395, 396] as well as social acceptability. Timely and adequate diagnosis is of paramount importance for the patient's quality of life [395, 396, 403, 404]. Urodynamic investigation is also essential in following up the natural history of the disease or for checking the efficacy of treatment. Elevated detrusor pressure during filling or voiding puts the upper urinary tract at risk. The primary aim of therapy in patients with this condition is conversion to a low pressure bladder during filling [313, 396], even if this causes incomplete emptying. Adequate therapy depends on whether the detrusor is hyperreflexic or has reduced compliance, and only urodynamics can answer those questions unequivocally.

Since the neuropathic bladder is sensitive to the filling rate, filling may start at 10ml/min and be slowly increased slowly up to 20 or 30 ml/min. If the detrusor pressure begins to rise, the filling should be temporarily halted until the pressure falls or equilibrates. During the filling phase, patients with a neuropathy, especially those with a high spinal cord injury, may develop autonomic dysreflexia. This is a dangerous syndrome necessitating continuous blood pressure monitoring. If the blood pressure rises, the test should be terminated and the bladder should be emptied immediately.

V . CHILDREN

The indications for urodynamic evaluation in children can be divided along neurologic, anatomic and functional lines. The types of studies to be performed are based on the underlying pathologic condition rather than the presenting symptom.

1. Neurogenic bladder dysfunction

For children with myelodysplasia, urodynamic studies need to be performed soon after the back has been closed and the child is stable neurosurgically, generally within the first 2 to 3 weeks of life [266]. Cystometry looking for hyperreflexia and/or low compliance, detrusor leak point pressure, electromyography (EMG) of the external urethral sphincter and residual urine measurement are the key elements of a detailed urodynamic study. This provides not only a baseline for future comparison but also a means of determining those children at risk for deterioration of their upper urinary tract [102, 405]. Cystometry is repeated or indicated for the first time in older infants and children if they develop new onset hydronephrosis, reflux or incontinence [406, 407]. In older children on a continence program already (i.e. clean intermittent catheterization and/or drug therapy) any new incontinence not related to urinary infection nor easily treated by increasing their current regimen should be assessed by repeating cystometric, urethral pressure profilometric and EMG studies, if available [408]. A considerable number of children (40% or more) have progressive neurologic deficits as they grow up and reach puberty [409, 410]. Monitoring their external urethral sphincter EMG periodically during the first 3 to 6 years of life and then periodically with (1) any change in leg function, (2) development of incontinence despite strict adherence to current bladder and bowel continence programs, or (3) back pain or increasing scoliosis, is the most accurate way to detect a change in function. A CMG/EMG should be performed 3 months following any neurosurgical intervention to correct a tethered cord, or if scoliosis surgery has been performed that leads to changes in leg function or increased incontinence.

For children with an occult spinal dysraphism, cystometric and EMG studies are necessary preoperatively, and 3 months postoperatively following correction of the spinal defect [411, 412]. This helps the neurosurgeon to clarify the status of the sacral spinal cord pre- and postoperatively, and to use this information to determine if progressive changes occur over time, postoperatively. Twenty to 35% of infants and children under 2 have no apparent neurologic deficits grossly but suffer from upper and/or lower motor neuron injury to the bladder and urethral sphincter, preoperatively [411, 413, 414]. Less than 10% have a change in function from their surgery directly, while a variable number improve their sacral cord function, depending on the age of intervention [411, 415, 416]. With axial growth, 25 to 35% develop progressive denervation [414, 417, 418] documenting this change and treating the incontinence problems require a detailed urodynamic study.

Sacral agenesis is a lesion that is often missed in infancy because of its subtle manifestations, with generally no loss of lower extremity motor and sensory function [419]. Urinary and/or fecal incontinence at an older age are usually the issues that lead to the diagnosis. Because both upper and/or lower motor neuron lesions of the bladder and external urethral sphincter are possible regardless of the level of absent vertebrae, a detailed urodynamic study is indicated [420 - 422] The lesion tends to be non-progressive with this disorder, so characterizing its extent and treating it appropriately at the time of diagnosis is sufficient.

Spinal cord injuries in children are fortunately quite rare [423] For those patients who regain the ability to void spontaneously, it is imperative to know if they have low filling and emptying pressures. Thus, after the initial spinal shock from the injury wears off cystometry, sphincter EMG and residual urine measurements are necessary [424 - 426]. Cauda equina injuries may require assessment of urethral pressure as well, due to the neurologic lesion affecting the external sphincter muscle. For those children who are continent on intermittent catheterization cystometry with sphincter EMG is needed regardless, in order to insure low bladder filling pressures and absence of hyperreflexia during filling. Balanced voiding with pressures below 40 cm H_2O will insure a stable upper urinary tract [427]. When filling and voiding pressures are elevated there is a 30% incidence of upper urinary tract deterioration [207].

Cerebral palsy is a non-progressive disease of the cerebral cortex or brainstem [428]. Affected children tend to toilet train completely, albeit at an age later than normal children [424]. Most of the time their incontinence is secondary to urgency and an inability to be toiletted on time. Dribbling in between voidings is almost never seen. Studies have shown that the children have either a normal urodynamic examination or exhibit signs of upper motor neuron dysfunction with hyperreflexia; very rarely is dyssynergia between the bladder and urethral sphincter noted during voiding [429, 430]. As a result, cystometry and sphincter EMG are needed when anticholinergic therapy fails to control the incontinence, the children are unable to empty their bladder completely when they void or an ultrasound shows hydronephrosis and a thick walled bladder.

2. Imperforate anus

Imperforate anus, as the name implies, occurs when the anal canal fails to cannulize to the surface ectoderm in the area of the future rectum. A classification system has been devised in which lesions are divided into high, intermediate or low depending on whether or not the rectum ends above, at or below the levator ani muscle. In the past imperforate anus repair for high lesions often resulted in urinary incontinence due to pudendal nerve injury that occurred from the perineal approach to bringing the rectum down to the anal verge [431]. With the advent of the posterior sagittal anoplasty this complication was eliminated as a cause for subsequent urinary incontinence, although bladder neck incompetence may be a consequence of extensive mobilization of the sigmoid colon which helps transfer the rectum to its final location. In addition, it has been noted recently, that distal spinal cord abnormalities are present on magnetic resonance imaging even in the absence of overlying skin manifestations, in 35% of children with imperforate anus [420, 432, 433]. Therefore, videourodynamics and EMG of the sphincter are indicated in any of these children who have a bony abnormality of the spine, an abnormal renal ECHO or VCUG suggestive of neurogenic dysfunction or are incontinent beyond the normally accepted toilet trained age [434].

The VATER or VACTERL association is a group of diverse abnormalities that include Vertebral bony, Anal atresia, Cardiac, Tracheo-Esophageal fistula, Renal and Limb anomalies [435]. Imperforate anus may occur as an isolated lesion or in conjunction with this association. Urinary incontinence is not common unless the spinal cord is involved (20%). Various defects of the spinal cord can be noted producing a picture of either upper and/or lower motor neuron type lesions to the lower urinary tract [420, 434, 436]. Videourodynamic studies are indicated soon after the diagnosis is made, especially if radiologic imaging demonstrates a spinal cord abnormality. These studies serve as both a reason to explore and treat any intraspinal abnormality to improve the child's chances of becoming continent of both urine and feces, and as a basis for comparison, especially if incontinence should become a problem in the future.

3. Anatomic

Anatomic abnormalities constitute a whole different set of indications for urodynamic evaluation. Boys with posterior urethral valves may present with hydronephrosis *in utero*, urinary infection in infancy and incontinence in childhood. Ablation of the valves often leads to improvement of upper urinary tract dilation and symptoms of incontinence, but in a substantial number (20 to 25%), there is no appreciable change in bladder function [437, 438]. Characterizing the bladder function during its filling and emptying phases, pre- and post resection of the valves provides the necessary parameters for improving the functional state of the lower urinary tract. [439, 440] Medical treatment may be instituted based on persistent abnormal findings of detrusor muscle function [441]. Exstrophy of the bladder can be a daunting problem to manage. Most children have their exstrophied bladder closed in the neonatal period with subsequent staged reconstruction of the bladder neck and epispadiac urethra performed at variable times in infancy and early childhood. There is a tendency now to close the bladder and complete the urethroplasty simultaneously in the newborn period. Although 15 to 20% achieve continence following the initial closure only [442], cystometry, urethral pressure profilometry and residual urine measurements are needed to characterize the status of the lower urinary tract at various stages of the reconstruction and to determine what surgical procedure or medical regimen may be needed next, in order to achieve continence [443]. Urinary incontinence following surgical excision of a ureterocele that extends down past the bladder neck to the external urethra (caecosphincteric ureterocele) may be due to an injury to the bladder neck and/or the external urethral sphincter mechanism. There is sparse evidence that this form of bladder outlet obstruction affects detrusor muscle function. Static and dynamic urethral pressure profilometry and videourodynamic studies of the bladder neck are indicated when incontinence follows treatment of this condition.

The presence of vesicoureteral reflux after apparently successful antireflux surgery warrants cystometry and a voiding pressure study. Hyperreflexia, elevated voiding pressure, significant residual urine and poor elimination habits should be determined and managed in order to help resolve the persistent postoperative reflux in a non-invasive manner. Urethral stricture disease in boys is a rare event, arising most likely from an unsuspected straddle injury in the past. A urinary flow rate pre- and postoperatively after either endoscopic or open surgery for this condition can demonstrate to the boy, the marked change in his ability to void normally. Because recurrence of a stricture may be insidious, periodic monitoring of the urinary flow rate for peak and mean values, and evaluating the characteristics of the urine stream may alert the clinician to early signs of renarrowing.

4. Functional

When assessing functional disorders involving the lower urinary tract in children, one must take into account the dynamics of the maturing nervous system, learned habits of elimination for bladder and bowel function and social influences that might modulate the child's behavior [444, 445].

Day and nighttime incontinence is not considered a worrisome issue until age 5 or 6. Then, most children without an unsuspected anatomic or neurologic lesion should be dry [446]. Persistent day incontinence in the absence of urinary infection and with a normal bladder and bowel emptying regimen warrants cystometry, pressure flow studies and a urinary flow rate. Stress incontinence in girls and adolescent females is rare but should be delineated with cystometry, pressure flow studies and video urodynamics or ambulatory urodynamics, if simple measures to insure regular emptying do not work.

Nighttime wetting (enuresis) is a condition that often improves over time [445 - 448] Although there may be social and familial pressures to resolve the condition in various cultures before puberty, in western cultures it is generally not necessary to conduct urodynamic studies until adolescence, to determine why it has not resolved. Urodynamic testing in a home setting, such as provided by ambulatory monitoring may be an ideal method to characterize why these children have continued enuresis.

Daytime wetting as an isolated symptom in boys without nocturnal enuresis nocturna rarely warrants lower urinary tract investigation [449]. If no anatomic abnormality is present on radiologic studies it is unlikely there will be any aberration on urodynamic testing. Girls with day wetting only may have vaginal trapping of urine with subsequent postmicturition leakage. A thorough physical examination and careful questioning of when the incontinence occurs should help to define and treat the problem. Urgency or sudden incontinence throughout the day in the absence of infection should be treated with anticholinergic drugs initially; cystometry is indicated if incontinence persists despite medical therapy.

Fecal incontinence in the absence of any anatomic and/or neurologic deficit often affects lower urinary tract function and contributes to urinary incontinence in a number of ways. Constipation and fecal impaction have been shown to cause detrusor overactivity and reduced functional bladder capacity [450]. Monitoring the effectiveness of colonic emptying and assessing bowel contents during videourodynamics may provide an explanation for the lower urinary tract dysfunction noted during these studies and pose an easy, effective answer for treatment. Alternatively, fecal soiling from constipation or poor hygiene may lead to urinary infection which can then alter both detrusor and urethral function. Understanding and eliminating this etiology may normalize lower urinary tract function without the need for urodynamic studies [451].

Urinary infection is a major cause of incontinence in girls, because it can lead to low compliance, and detrusor and/or urethral instability. It can arise from a multitude of causes. As noted, bowel dysfunction may lead to its occurrence [452]. In fact, dysfunctional elimination "syndromes" are now considered the primary and not a secondary cause of recurrent urinary infection and in some cases the etiology for vesicoureteral reflux [451]. Treating these elimination disorders is paramount to surgery for reflux in many instances [451, 453]. In addition to systemic and local host factors, abnormal voiding dynamics from learned behavior patterns, aberrant voiding habits and poor hygiene are likely causes of recurrent UTI in girls [454].

Urodynamic studies in infants < 6 months of age with reflux reveal an overactive bladder in 50% and high voiding pressure in 95% [455]. With increasing age, voiding pressures diminish to normal values and overactivity resolves in most children, suggesting the presence of a transient form of bladder outflow obstruction in infants with severe reflux [456]. Similar findings were noted by several investigators assessing newborns with severe reflux [457] [458]. These studies in infants and the association of dysfunctional elimination syndromes with reflux and infection in older children strongly suggest that vesicoureteral reflux is a secondary disorder related more to abnormal bladder function than to a primary anatomic defect at the ureterovesical junction. Urodynamic studies are indicated (1) in the absence of reflux, but when voiding cystography reveals trabeculation and/or diverticulum formation, with abnormalities in the appearance of the bladder neck and urethra; (2) when there is persistent incontinence and/or recurrent infection despite long term antibiotics and anticholinergics, respectively; and (3) with an interrupted urine stream and an elevated residual urine [459]. A urinary flow rate prior to any instrumentation in a relaxed setting in order to recreate a representative flow rate is probably the single most important test to obtain [460]. An intermittent flow pattern secondary to incomplete relaxation of the sphincter throughout voiding and incomplete emptying are a likely consequence of, as well as etiology for, recurrent UTI. Videourodynamics which include bladder and urethral pressure monitoring during the filling and emptying phases of the micturition cycle can provide numerous clues, when the actual flow rate curves are normal. Sphincter EMG may be necessary as well when dyssynergia between the detrusor and sphincter is suspected.

5. Technical concerns

A reduced rate of filling, i.e. 10% of the expected bladder volume per minute, is recommended. Expected bladder volumes are noted in section 2.1.d. The smallest dual-channel urethral catheter available should be used in children for the same reasons as specified for adults. Most children can undergo studies without premedication; only the most agitated may require some degree of sedation. A suprapubic catheter placed under anesthesia the day before may make the subsequent investigations more accurate in cases of a very small caliber urethra or when a precise assessment of urethral competence is needed. It has been employed to monitor bladder pressure during natural fill cystometry.

VI. FRAIL ELDERLY

Elderly patients should not be considered differently from younger subjects simply because of their chronological age. That symptoms poorly predict urodynamic diagnosis is also true in the elderly [461], [462]. Questionnaire surveys, which have been frequently used in epidemiological studies, are known to correlate poorly with extended urodynamic testing [463]. Urodynamic findings in the elderly tend to demonstrate an overactive detrusor [464], [465], and a reduction in bladder capacity, urinary flowrate and detrusor contractility [466]. Symptoms such as urgency, frequency and incontinence are more frequently detected in aged men and women [466]. However, these changes in urodynamic and symptomatic findings associated with aging are not necessarily interrelated. For example, in a large community survey, only 12% of incontinent women and almost 5% of continent women were found to have involuntary detrusor contractions [467]. Meanwhile, other studies showed that 11% to 42% [464], [468] of continent elderly women demonstrated involuntary contractions on conventional cystometry. These observations indicate that more detailed examinations are needed to disclose the underlying pathophysiology in the incontinent elderly [461 - 463]. In fact diverse types of lower urinary tract dysfunction are shown to be involved in incontinence in the elderly by multichannel videourodynamics [465].

On the other hand, frail elderly patients may require special consideration. Most of them will not undergo surgical or invasive treatments for their incontinence. In this setting the Minimum Data Set and Resident Assessment Protocol [469], when administered by trained staff, provided a stepwise and non-urodynamic diagnosis of the type of incontinence without serious misclassification [470].

Among urodynamic investigations, measurement of post-void residual urine is important. If it is small, significant infravesical obstruction or detrusor underactivity or acontractility is unlikely, and a small dose of anticholinergic medication may be tried. If a large amount of residual urine is found, overflow incontinence or incontinence associated with infection is suspected, and intermittent catheterization may be indicated. The measurement is included in the Resident Assessment Protocol along with the stress test [470].

If cystometry is indicated and no equipment or referral is available, it can be modified to "simple cystometry" [87] The procedure needs only an open syringe attached to a single lumen catheter, sterile water or saline and a tape measure. Fluid is infused by gravity at a pressure head of 15-20 cm H_2O. Bladder capacity, sensation of filling, and presence of a detrusor contraction or overactivity can be semiquantified. Pressure is measured by observing the height of the column of water. These simple measures can be carried out at the bedside and may be useful for disabled patients [89 - 91], [471], [472]. Simple cystometry, as compared with multichannel cystometry, has a specificity of 79% or 75% and a sensitivity of 75% or 88% for the observation of detrusor overactivity [89], [90]. The accuracy can be improved by combining it with simpler tests [90], [91] or with a stress test to exclude stress incontinence [21]. Thus, simple cystometry can be helpful to assess bladder function among geriatric patients in whom formal urodynamics are either unavailable or impractical.

However, the clinical significance of these findings is limited. Detrusor overactivity is found in up to 50% of *symptom-free* elderly, while detrusor overactivity incontinence is the most likely finding in *incontinent* frail elderly in any case [465], [473]. Furthermore most of the studies recommending simple cystometry were conducted before a high prevalence of detrusor hyperactivity with impaired contractility (DHIC) was recognised [465]. This dysfunction is the most common abnormality in incontinence observed in frail elderly populations [465], [473], and is easily misdiagnosed as a stable detrusor by simple cystometry [21], because single channel cystometry is less sensitive for detecting low-pressure detrusor contractions. If a contraction coincides with a cough, the leakage may be regarded as the sign of a positive stress test. Further research is needed to estimate predictive values of non-urodynamic assessment, simple cystometry with or without simpler tests, or further referral investigation in the frail elderly.

E. CONCLUSIONS

I. GENERAL CONCLUSIONS

- Urodynamic investigation is the only means of objectively assessing lower urinary tract function or dysfunction in incontinent patients. Therefore it should be performed in clinical research and is required in clinical practice whenever detailed knowledge of lower urinary tract function is needed to decide on treatment, to help predict the outcome of treatment, or to understand the reasons for failure of treatment.
- Adherence to standardized well-documented methods is critically important to ensure the clinical and scientific reliability and reproducibility of study results. Clearly defined and widely accepted standard terminology, e.g. the terminology developed by the ICS, for describing urodynamic results facilitates straightforward and unambiguous communication.
- Urodynamic investigation by itself is inadequate to define the cause of lower urinary tract dysfunction and its consequences. Integration of symptoms, voiding diary, history, physical findings, radiologic imaging and all the results of urodynamic study are essential for the correct assessment.
- The indication for each urodynamic examination should be tailored to the individual patient in the light of the diagnostic strategy and the potential predictive value of the results it will provide.

II. RECOMMENDATIONS FOR CLINICAL PRACTICE

The following recommendations have been graded as either grade C (based on level 4 evidence from case series) or grade D (based on level 5 evidence: i.e., expert opinion). All have unanimous committee agreement.

- Investigation should only be performed in women if voiding difficulty or neuropathy is suspected, if previous surgical or non-surgical treatments have failed, or if invasive or surgical treatments are considered (Recommendation grade C).
- In men and children detailed urodynamic investigation should be undertaken (Recommendation grade D).
- Uroflowmetry with residual urine measurement and filling cystometry with and without provocation (tailored to the patient's condition) should be employed as a first-line investigation (Recommendation grade C).
- Gas cystometry is not recommended (Recommendation grade D).
- If it is necessary to estimate urethral competence during the filling phase, urethral pressure profiles and/or abdominal leak point pressure measurements are indicated (Recommendation grade C).
- Urethral function during the voiding phase should be evaluated by pressure-flow studies or videourodynamics, ± electromyography especially if neuropathy is evident (Recommendation grade D).
- Videourodynamics may be used to detect leakage and morphological abnormality simultaneously with pressure monitoring (Recommendation grade D).
- Ambulatory urodynamic monitoring might be considered for those who fail to demonstrate leakage or detrusor overactivity in other investigations (Recommendation grade D).

III. RECOMMENDATIONS FOR FUTURE RESEARCH

1. Research on clinical relevance

- To remedy the paucity of high-quality evidence for or against the utility of urodynamics in the investigation of incontinence, properly conducted, large-scale, randomized controlled trials are urgently needed to determine the role, predictive value, and effect on treatment outcomes of urodynamics, videourodynamics and ambulatory monitoring. Such trials should be conducted for various patient groups in various clinical settings
- Investigation of the predictive value of urodynamic findings for treatment outcomes

2. Research on methodological aspects

- Standardization of:

  methods for quality control of urodynamic equipment;

  techniques and instrumentation;

training and qualifications of personnel;

documentation of results.

- Development of improved techniques for assessing bladder sensation.
- Minimization of the invasiveness of urodynamic techniques (e.g., refinement of ultrasonic imaging techniques) so that they are more widely applicable and can be carried out in more natural settings, with a minimum of personnel and expense.
- Development of methods of quantification of urodynamic observations, to improve reliability, interchangeability, and clinical relevance.

3. Research on interpretational aspects

- Precise determination of physiological, technical and interpretation variability of urodynamic results.
- Revised terminology to describe urodynamic findings more precisely and clearly, especially in the field of urge incontinence, detrusor overactivity, and bladder sensation.
- Development of an improved urodynamic definition for intrinsic sphincter deficiency based on the understanding and characterization of the underlying pathophysiology.

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