Urodynamics
Paul Abrams

Urodynamics

Third Edition

With 152 Figures

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Lower urinary tract dysfunction produces a huge burden on sufferers in particular and on society in general. Lower urinary tract symptoms have a high prevalence in the community: 5% of children aged 10 wet the bed, while 15% of women and 7% of men have troublesome incontinence; and in elderly men of 75, benign prostatic hyperplasia occurs in more than 80% of individuals, with benign prostatic enlargement coexisting in up to half this group and half of these having bladder outlet obstruction.

The confusion felt in many people's minds as to the role of urodynamics has receded for the most part. The need to support the clinical assessment with objective measurement has become accepted by most clinicians specialising in the care of patients with lower urinary tract symptoms (LUTS). Since the first edition of this book in 1983, urodynamics has become more widely accepted. In the last 20 years the number of urodynamic units in Britain and Europe has increased rapidly and almost every hospital of any significance embraces urodynamic investigations as an essential part of the diagnostic armamentarium of the urology and gynaecology departments. Further, specialists in geriatrics, paediatrics and neurology recognise the importance of urodynamics in the investigation of a significant minority of their patients.

Despite the technological innovations that have seen the introduction of computerised urodynamics, the development of neuro-physiological testing and the introduction of new techniques such as ambulatory monitoring, the objectives of this book remain unchanged. Urodynamics may appear complicated, and one of the objectives of this book is to put the subject over simply but in enough detail to allow urodynamic investigation to be accepted, on its own merit, as a fundamental contribution to the management of many patients. To do this means not only describing the tests but also showing in which clinical areas they help management and in which they are pointless. It means concentrating on the common clinical problems and on the presenting symptom complexes, not the diagnosis; and it means pointing out any limitations and possible artifacts of investigation.

We hope that a clinician with no previous experience in urodynamics will, after reading this book, appreciate both the value and limitations of the subject, and will have obtained the necessary practical advice on the use of the appropriate equipment in the correct situations. Because this book is based on personal experience, references in the text are relatively few.
The scientific basis of urodynamics does not change and the principle reason for producing the 3rd edition has been the publication in 2002 of the new ICS terminology report 2002 together with the ICS reports on “Good Urodynamic Practice” (2002).

Bristol Urological Institute

2005

References


<table>
<thead>
<tr>
<th>Abbreviation</th>
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<tbody>
<tr>
<td>AUDS</td>
<td>ambulatory urodynamic studies</td>
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<tr>
<td>BOO</td>
<td>bladder outlet obstruction</td>
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<td>BPE</td>
<td>benign prostatic enlargement</td>
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<td>BPH</td>
<td>benign prostatic hyperplasia</td>
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<td>BPO</td>
<td>benign prostatic obstruction</td>
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<tr>
<td>DFV</td>
<td>dysfunctional voiding</td>
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<tr>
<td>DSD</td>
<td>detrusor sphincter dyssynergia</td>
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<td>DUA</td>
<td>detrusor underactivity</td>
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<tr>
<td>GP</td>
<td>general practitioner (family physician)</td>
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<td>ICS</td>
<td>International Continence Society</td>
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<td>IDO</td>
<td>idiopathic detrusor overactivity</td>
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<td>ISC</td>
<td>intermittent self-catheterisation</td>
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<td>LUTD</td>
<td>lower urinary tract dysfunction</td>
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<td>LUTS</td>
<td>lower urinary tract symptoms</td>
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<tr>
<td>MCUG</td>
<td>micturating cystourethrography</td>
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<td>MUCP</td>
<td>maximum urethral closure pressure</td>
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<td>NDO</td>
<td>neurogenic detrusor overactivity</td>
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<tr>
<td>P&lt;sub&gt;abd&lt;/sub&gt;</td>
<td>abdominal pressure</td>
</tr>
<tr>
<td>P&lt;sub&gt;det&lt;/sub&gt;</td>
<td>detrusor pressure</td>
</tr>
<tr>
<td>PFS</td>
<td>pressure-flow studies</td>
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<tr>
<td>P&lt;sub&gt;ves&lt;/sub&gt;</td>
<td>intravesical pressure</td>
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<td>PVR</td>
<td>post-void residual</td>
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<tr>
<td>Q&lt;sub&gt;ave&lt;/sub&gt;</td>
<td>average flow rate</td>
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<tr>
<td>Q&lt;sub&gt;max&lt;/sub&gt;</td>
<td>maximum flow rate</td>
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<tr>
<td>TURP</td>
<td>transurethral resection of the prostate</td>
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<td>urodynamic studies</td>
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<td>urine flow studies</td>
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<td>urethral pressure profile</td>
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<td>urodynamic stress incontinence</td>
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<td>VUDS</td>
<td>videourodynamic studies</td>
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<td>VUR</td>
<td>vesico-ureteric reflux</td>
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### Measurement Units

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<td>volume</td>
<td>millilitre (ml)</td>
<td>V</td>
</tr>
<tr>
<td>time</td>
<td>second (s)</td>
<td>t</td>
</tr>
<tr>
<td>flow rate</td>
<td>millilitres/second (ml/s)</td>
<td>Q</td>
</tr>
<tr>
<td>pressure</td>
<td>centimetres of water (cmH₂O)</td>
<td>P</td>
</tr>
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### Urodynamic Qualifiers

- Intra vesical (bladder): ves
- Intra urethral: ura
- Detrusor: det
- Abdominal (usually rectal): abd
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Chapter 1

Principles of Urodynamics

Urodynamics has two basic aims:

● To reproduce the patient's symptomatic complaints during urodynamics, and
● To provide a pathophysiological explanation by correlating the patient’s symptoms with
  the urodynamic findings.

Implicit in these aims is the acceptance that whilst the patient’s symptoms are important,
because they bring the patient to the clinician, they are often misleading. Most patients with
lower urinary tract dysfunction present to their doctor with symptoms, but in all branches
of medicine symptoms have been shown to be misleading to a varying degree. Were symp-
toms reliable, further investigation would not need to precede active management. At one
time, the elderly male patient with lower urinary tract symptoms (LUTS) would automati-
cally have been offered a prostatectomy and, similarly, a woman with LUTS would have had
an anterior repair with or without a hysterectomy. Most of the published literature indicates
that the symptoms of lower urinary tract dysfunction (LUTD) are unreliable. Previously,
clinicians appreciated the need for some investigations and chose to assess the lower
urinary tract using “static” investigations, such as intravenous pyelography (IVP) and
cystourethroscopy. However, the lower urinary tract, both during filling and emptying, is a
dynamic system. Hence it is appropriate to use dynamic investigations for the investigation
of lower urinary tract problems.

The statement “the bladder is an unreliable witness” was made by Bates in 1970 in one of
the early papers on urodynamics (Bates et al., 1970). Two important papers appeared in
1980. One by a gynaecologist, Gerry Jarvis (1980) found that of 100 patients diagnosed by
their symptoms as having stress incontinence, only 68 were shown to have urodynamic
stress incontinence. This was supported by the findings of Powell (working in the Bristol
unit; Powell et al., 1980) that only 50% could be shown to have urodynamic stress inconti-
nence. Both authors also looked at patients with apparent overactive bladder symptoms
presumed to be the result of detrusor overactivity. Jarvis confirmed this diagnosis in only
51% of cases, while Powell showed detrusor overactivity in only 33% of such patients.
Further work in women has shown that in women presumed to have urodynamic stress
incontinence, 12% had another cause for their stress incontinence. In most patients, factors such as change of posture, leading to the apparent stress incontinence, provoked detrusor overactivity, leading to the reported incontinence. Clearly in this group of patients, with apparent stress incontinence, surgery would have been unsuccessful in at least the 12% who were suffering from an altogether different type of problem. These papers illustrate the difficulty of assessing women with lower tract dysfunction by symptoms alone. As in women, LUTS in the males are of poor diagnostic value. Furthermore, the findings from IVP and cystoscopy have been shown to be poor indicators of bladder outlet obstruction. Both Abrams (1978) and Andersen (1979) have shown that the symptoms of apparent prostatic obstruction are misleading. Of the many symptoms that the textbooks attribute to prostatic outlet obstruction, they could show that only slow stream and hesitancy bore any correlation with the urodynamic findings of obstruction, that is, high voiding pressure and low urine flow rate. Because symptoms have been shown to lack diagnostic specificity in all clinical groups, it is not surprising to find that when surgery was based on symptoms alone the results were less than satisfactory. The decision to recommend prostatic surgery was previously indicated by an assessment of symptoms backed by the findings from IVP and cystourethroscopy. Early audit of prostatectomy assessed by these means showed a cure rate of only 72%, poor for an elective procedure. Urodynamic studies provided alternative explanations for many symptoms and, when dynamic investigations of function (urodynamics) rather than static investigations of structure (IVP and cystoscopy) were used in preoperative evaluation, the results of surgery improved to 88%.

The preceding discussion relates to men and women who are neurologically normal and therefore able to appreciate sensation from their lower urinary tract. In patients who have neurological conditions affecting the lower urinary tract, it is common for sensation to be absent or abnormal, making their symptomatic complaints even more difficult to interpret.

Faced with the unpalatable fact that patients submitted for surgery without objective confirmation of their condition did rather poorly, surgeons reacted in different ways. Some became ostrich-like, and dismissed those who published these results as poor surgeons bereft of clinical acumen and operative skills, while making no effort to assess their own results. Others, who had always been uneasy about patient assessment by symptoms and non-functional studies, such as intravenous pyelography, seized the opportunity to study these large groups of patients by urodynamic means. Hence in the 1970s there was a rapid expansion of clinical and research urodynamics. The wider acceptance of urodynamics has allowed us to look at LUTS from a different perspective.

The Urodynamic History

Despite the shortcomings of the patient’s symptoms for diagnosis, they are important. They trouble the patient sufficiently for him or her to seek medical help, and LUTS should be assessed in a systematic way.

Some quarters have taken a nihilistic approach to urodynamic investigations because of the alleged inadequacy of this method of assessment and on the premise that if the patient’s symptoms are improved by an intervention (e.g., an operation), then nothing else matters! However, because the patient’s symptoms and the objective urodynamic findings bear little relationship to each other, this approach has several major drawbacks. Already mentioned are the less than adequate results from elective surgery, when only symptoms were considered in diagnosis. Second, there is a well-established, very large placebo effect in patients with LUTS. The symptoms of men with proven bladder outlet obstruction, secondary to
benign prostatic hyperplasia, can be improved by placebo treatment to such an extent that 40% to 60% of men in the placebo arm of drug studies consider themselves considerably improved.

Nevertheless, doctors and nurses familiar with urodynamic techniques and with a functional appreciation of bladder and urethral physiology are able to take a history from a patient that gives a much more accurate picture of the patient's real problems. The significance of individual symptoms and groups of symptoms is discussed in detail in Chapter 4.

The Urodynamic Physical Examination

Patients referred for urodynamics will have been examined in a general way, either in the hospital clinic from which the referral emanated, or by the patient's general practitioner (primary care physician). Hence the urodynamic staff should concentrate its efforts on a physical examination that will shed light on the patient's symptomatic complaints and the underlying pathophysiological processes that could have caused these complaints. One of the great advantages of the Bristol unit is that adequate time is given for close questioning, the relevant physical examination, an unhurried urodynamic investigation and practical advice. The importance of the urodynamic physical examination is discussed in detail in Chapter 4. Urine examination should be performed in all patients, and radiology and endoscopy have their indications, as will be discussed in Chapter 4. Urinary studies should follow only when careful investigations have been performed to exclude other pathologies that might mimic lower urinary tract dysfunction.

The Aims of Urodynamics

The objectives of any test can be achieved if the appropriate questions that the test is designed to address are posed. Therefore, at the outset, it is important to ask the following question:

"What do I want to know about this patient?"

Urodynamic studies have their limitations. It may be useful for the clinician to answer this question in terms of the filling and voiding phases of the micturition cycle and in terms of the bladder and the urethra. In this way, the urodynamicist can ask the next relevant question, which is:

"Which urodynamic investigations need to be performed to define this patient's problems?"

This question will concentrate the clinician's thought processes on eliminating those investigations which cannot help to make the diagnosis or indicate the line of management. For example, if a young male patient has had a urethral stricture and restricturing has to be excluded, then urine flow measurement will be the only required test.

Once the questions that need to be answered have been defined and the relevant urodynamic tests selected, the next question should be:

"Is the investigation likely to be of benefit to the patient?"

This question, again, can be answered by an analysis of the possible benefits to the patient, in terms of the increased knowledge generated by the test, and the influence this knowledge
will have on his or her clinical management. Even when knowledge does not appear likely
to improve the quality of life of that patient, there may still be an overall benefit to them if
knowledge in a difficult area without effective treatment techniques can be increased. An
increase in knowledge may, at a future date, result in the introduction of effective treatment.
A good example would a young woman who cannot void adequately. When often normal
voiding cannot be re-established, intermittent self-catheterisation is a good treatment,
although it is resented by many patients. However, routine investigations usually contribute
little to effective management, although neurophysiological testing may show abnormal
sphincter activity. Hence investigations may show the cause, although the clinician does not
have the means to reverse these abnormalities.

The benefits of the investigations must be set against the potential harm the tests could
do. Fortunately, urodynamics are a relatively harmless investigation, although there is a
small incidence of urinary tract infection (1% to 2%) and some discomfort. Then, there is
the question of whether the information gained by the tests offsets their financial cost. Also
important in deciding the benefit-risk analysis of the investigations will be the answers
given to the following questions.

“Is urodynamics able to make a reliable diagnosis?”

This is a complex question within which the fundamental query is whether the tests
themselves are reliable and reproducible. Three factors greatly influence the value of
urodynamics:

● The urodynamic technique should be free of technical artefacts.
● The results of investigations should be reproducible.
● The clinician should be properly trained and able to interpret the results of
  urodynamics.

From a technical point of view, the tests must clearly be carried out in a careful way, elimi-
nating all possible artefacts. This aspect of urodynamic studies is discussed extensively in
Chapter 3. The patient's own bioconsistency is another problem. We know that symptoms
vary considerably with time, but we do not have much information as to whether or not
urodynamic findings vary. This problem is best dealt with at the end of the urodynamic tests
by asking:

“Did the urodynamic studies reproduce the patient’s complaints and did the complaints
correlate with known urodynamic features?”

In the Bristol unit, we have always laid great emphasis on the clinician, who is aware of the
therapeutic possibilities of subsequent treatment, being present during urodynamics. The
clinician can then be sure whether the sensations felt by the patient and the findings demon-
strated by urodynamics are typical of the patient's everyday symptoms and whether any
urodynamic abnormalities can account for these. Occasionally during urodynamic studies
either the patient complains of an unrepresentative symptom, for example, urgency, or there
is a urodynamic abnormality noted which does not correlate with the patient's symptoms.
These discrepancies can be detected and interpreted as artefacts, if the clinician is present.
However, if the urodynamics is delegated to a technician they may be reported on their face
value, leading to a possible bias in the report that may influence subsequent patient
management.
In some instances more than one abnormality can be seen, therefore it is important to ask:

"Can urodynamics decide which is the most significant abnormality if more than one is detected?"

Multiple abnormalities are commonly seen in patients with neurogenic vesicourethral dysfunction. They are also often seen in non-neurological patients, such as in women with mixed incontinence. Treatment should be directed to the most significant or troublesome abnormality. Hence, once again, the correlation between the patient’s symptomatic complaint and the urodynamic findings are most important. This correlation allows the clinician to advise on which abnormality is the most significant and should therefore receive management priority.

As well as seeking answers to the above questions the urodynamicist needs to define the indications for urodynamic investigation, and these can be viewed in a slightly different way:

- To increase diagnostic accuracy above that which can be achieved by nonurodynamic means.
- To make a diagnosis on which a management plan can be based. Overactive bladder symptoms are usually treated empirically on the assumption that detrusor overactivity is the cause, if a patient fails conservative and medical therapy, urodynamic proof of detrusor overactivity is required prior to invasive surgery.
- If there are coexisting abnormalities, to provide evidence to determine which should be treated first. In female mixed incontinence, determining which form of incontinence is most bothersome can be difficult. By careful assessment of the patient during urodynamics, it is usually possible to decide which is the predominant problem and thereby establish the treatment priority.
- To define the current situation, knowing the likely abnormalities, as a baseline for future surveillance. In spinal cord trauma, it is usual to perform urodynamic after spinal shock has resolved. These baseline urodynamics establish whether there is a detrusor contraction in reaction to bladder filling and whether or not detrusor-sphincter-dyssynergia (DSD) has developed. DSD, as discussed later, is a dangerous condition that can lead to poor bladder compliance, upper tract dilatation and renal impairment.
- To predict problems that may follow treatment interventions. Elderly men with prostatic obstruction and co-existing detrusor overactivity (DO) should be warned that whilst their urine flows and other voiding symptoms will be improved by TURP, OAB symptoms due to DO may persist.
- To provide evidence that influences the timing of treatment. In patients with neurological disease (e.g., meningomyelocele) being treated by antimuscarinics, ultrasound may show the development of upper tract dilatation. Urodynamics are vital to confirm whether or not poor bladder compliance is the cause. If so a procedure such as ileocystoplasty will be required.
- To exclude abnormalities which might interfere with the management of that patient. In neurological patients with stress incontinence, who are being considered for the implantation of an artificial sphincter, the urodynamic demonstration of poor bladder compliance would indicate the need for treatment of the bladder condition as well as implanting
the sphincter. Failure to deal with the bladder would be likely to produce worsening bladder compliance with effects on upper tract drainage.

- To assess the natural history of lower urinary tract dysfunction. Our unit, by investigating men and women studied more than 10 years ago is providing important evidence as to the natural history of voiding dysfunction in men and OAB and DO in both men and women.

- To assess the results of treatments designed to affect lower urinary tract function. Simple urodynamics tests, such as urine flow studies, should be used to audit the result of surgeries to relieve bladder outlet obstruction, for example after optical urethrotomy for urethral stricture.

After a brief description of the anatomy and physiology of the lower urinary tract in Chapter 2, subsequent chapters discuss urodynamic techniques (Chapter 3) and their applications (Chapters 5 and 6).

References


Chapter 2
Anatomy and Physiology

Introduction

Urodynamic investigations developed because of dissatisfaction with the assessment of patients and treatment results when management was based on symptom assessment and the definitions of anatomical abnormalities. Urodynamics attempts to relate physiology to anatomy, that is function to structure. A sound knowledge of anatomy and physiology form the basis for the effective assessment and treatment of patients. In addition, this knowledge can be used to critically evaluate the role of urodynamic studies in assessing patients with lower urinary tract symptoms (LUTS).

Although the bladder and urethra are described separately below, it should be remembered that they normally act as a reciprocal functional unit.

Urethral Structure and Function

Very often the urethra is considered only as a passive conduit for urine. The bladder is viewed as the more important and more active part of the lower urinary tract. One reason for this may have been the observation of Lapides that continence was maintained in the isolated bladder even when most of the urethra had been removed. Urethral function is here discussed first in an attempt to redress this balance. Indeed it would be possible to argue that the urethra is the controlling agent in the micturition cycle.

The urethral closure mechanism and hence urinary continence depends on active and passive factors. Its function may be classified as normal or incompetent on filling, and normal or obstructive on voiding.

Anatomy

It is always tempting to infer function from structure. In general, the following comments on anatomy give greater perspective to functional urodynamic observations. The terminology and general arrangement of the lower urinary tract are shown in Fig. 2.1.
Mucosa

In both sexes, the mucosa is organised in longitudinal folds that give the urethral lumen a stellate appearance when closed. This arrangement allows considerable distensibility. The surface tension may be a factor in urethral closure.
Submucosa

The submucosal layer is a vascular plexus. Zinner (1976) discussed the role of this layer in relation to inner urethral wall softness. He suggested that the submucosa acts in a passive plastic way to “fill in” between the folds of mucosa as the urethra closes. This occurs as the tension increases in the muscular wall of the urethra, and its effect is to improve the efficiency of the seal of the urethral lumen.

There is an extensive submucosal vascular plexus which may have more than a passive role. Huisman (1979) has suggested that myoepithelial cells are found in association with arteriovenous shunts. This would provide a means of controlling submucosal pressure. Others suggest that the vascular element may be an important factor in the urethral closure in females where it is difficult to attribute all the occlusive forces to urethral muscle. This also explains the presence of urethral pressure changes synchronous with the arterial pulse and may be the reason for some postural and menstrual pressure changes. Gosling was unable to confirm the anatomical basis for this vascular control. In women after menopause, oestrogen deficiency is thought to lead to a reduction in the turgor of the vascular plexus and hence to be, in part, responsible for the increase in LUTS.

Urethral Muscle in Females

The smooth muscle of the female urethra is arranged longitudinally. Gosling (1979) showed from acetylcholinesterase analysis that the dominant innervation is cholinergic. Virtually no noradrenergic nerves are seen. This may appear confusing at first because the majority of the measurable resting urethral pressure depends on the alpha-adrenergic activity, if studies using alpha-blocking drugs are to be believed (Donker et al. 1972). This leads to a choice of conclusions:

- There are alpha-receptors on the smooth muscle, but no nerves to produce the transmitter (noradrenaline). This conclusion seems illogical.
- The urethral smooth muscle does not produce the urethral pressure. This is not as improbable as it sounds, because the fibres are not circular, but longitudinal, and not very prolific.
- The alpha-adrenergic effects occur not on the muscle but at the level of the pelvic ganglia. This is the currently popular explanation.
- Alpha-blocking drugs have effects on the neuromuscular transmission that are not conventionally recognised.

There are two groups of striated muscle fibres in relation to the urethra, called intramural and peri-urethral by Gosling (1979). Intramural striated muscle bundles are found close to the urethral lumen, sometimes interdigitating with smooth muscle. In the female, these fibres are found in the greatest frequency anteriorly and laterally in the middle third of the urethra. In the adult female, they do not surround the urethra posteriorly to form a circular sphincter as in the male. The muscle is of a "slow twitch" type, rich in myosin ATPase, and adapted to maintain contraction over a relatively long period of time. No muscle spindles have been seen.

The pelvic floor is separated from the urethra by a layer of connective tissue and is histochemically and histologically different from the introurethral striated sphincter.

Urethral Muscle in Males

The smooth muscle of the preprostatic urethra in males is histochemically distinct from that of the detrusor and from urethral muscle in females. This muscle also forms the
The striated muscles in the male can be divided into the same two groups described above for the female. The innervation is similar. The intramural striated muscle is orientated circularly around the postprostatic “membranous” urethra as a distinct sphincter.

**Innervation of Striated Muscle**

The innervation of the intramural striated muscle is usually predominately from S4, with a smaller S3 component. The muscle is probably innervated both from the pelvic nerve as well as from the pudendal nerve. The nerve cell bodies are located in Onuf’s nucleus in the antero-lateral part of the sacral cord (S2-4). The pelvic floor itself, is innervated by the pudendal nerve and possibly branches of the pelvic nerves, on its inner (cephalad) surface.

**Receptor Sites and Neurotransmitters**

Much recent effort has been directed towards the analysis of receptors in the urinary tract. The distinction between experimentally demonstrable alpha- and beta-adrenergic receptor sites and innervation is not always clear. Alpha-adrenergic receptors, causing smooth muscle contraction when stimulated, produce their effects mainly in the bladder neck and the proximal 3 cm of urethra in both sexes. Beta-receptor activity is very weak in this area, although it is present over the bladder dome. Beta stimulation encourages bladder relaxation. Appreciation of these functions aids the understanding of the action of drugs on the prostatic capsule. It is richly provided with noradenergic terminals and little acetylcholinesterase has been found. It is agreed generally that this well-defined muscle represents the “prostatic or genital sphincter” designed to prevent reflux of ejaculate at the time of orgasm. Certainly we have observed changes in pressure in this part of the urethra during penile erection (Fig. 2.2), and these changes do not seem to occur during any part of the micturition cycle unless there is erection.

Fig. 2.2 Urethral pressure profile demonstrating the elevation of the pressure in the region of the bladder neck/preprostatic sphincter during penile erection.
urinary tract. However the appropriate sympathetic nerves may not even be present anatomically in the areas where receptors have been demonstrated.

The complex interrelation of nerves, transmitter substances and receptor sites has been the subject of controversy for years. Some of the reasons why progress is slow in this field are outlined below:

- Individual nerves may produce more than one neurotransmitter.
- Neurotransmitters may act on more than one type of receptor, producing different actions.
- Neurotransmitters may act in different ways at the same receptor site depending on their concentration.
- Neurotransmitters may interact with one another.
- There are considerable species differences in both neurotransmitters and receptors.

An example of fundamental controversy has been the question of the identity of the principal neurotransmitter to the detrusor muscle. The postganglionic parasympathetic fibres are presumed to be cholinergic in that they are associated with identifiable acetylcholinesterase. However if the transmitter is acetylcholine it should be blocked by atropine. Although some species are atropine-sensitive, the majority are not. This has led to the suggestion that another substance may be the principal neurotransmitter. Alternatively the receptor on the bladder muscle may have more nicotinic characteristics than muscarinic. Perhaps some receptors are not accessible to freely circulating atropine. Suggestions for alternative transmitters have included 5-hydroxytryptamine, purine nucleodes such as ATP, and prostaglandins. It is now believed that in normal function acetylcholine is the principal neurotransmitter, although the situation may be different in abnormal conditions, such as bladder outlet obstruction and detrusor overactivity, when ATP may be important. More work needs to be performed on human muscle preparations, so that a better understanding of bladder neuropharmacology emerges. Meanwhile the unpredictable response to the pharmacotherapy for detrusor overactivity merely emphasises our incomplete understanding of the pathophysiologica processes involved in lower urinary tract dysfunction.

Central Nervous Activity

As seen in Fig. 2.3, the organisation of central control is a complex business. It can, however, be reduced to several relatively simple concepts. Sensation from the lower urinary tract must be appreciated centrally and consciously if normal cerebral control is to function. The sensation of bladder fullness and of bladder contraction ascends in the anterior half of the spinal cord. It may be affected by damage in that area of the cord, for example, in anterior spinal artery thrombosis and bilateral spinothalamic tractotomy, as well as other spinal cord lesions. Sensation of activity in the pelvic floor ascends in the posterior columns.

Sensation must not only reach the conscious level when the subject is awake; it must also, by its collateral effects on the reticular formation perhaps, be able to wake the subject from sleep or otherwise subconsciously to inhibit micturition. This may be the fundamental problem in nocturnal enuresis.

Assuming sensation is normal, the brain acts by balancing the various facilitatory and inhibitory effects suggested in Fig. 2.3, and the final common efferent pathway is through the “bladder centre” in the pontine reticular formation. This centre is essential for normally co-ordinated micturition. It acts on the sacral micturition centre in the conus medullaris, where the final integration of bladder and urethral activity takes place. Because the usual response of a bladder liberated from cerebral control is one of detrusor overactivity, it is assumed that the major cerebral output is one of tonic inhibition, hence the old term...
“uninhibited bladder”. However this is only an assumption, and prejudging the activity of
the nervous system can only slow down the understanding of it. We suggest that terms
which imply specific pathophysiology should be avoided as much as possible. The detailed
neurological control of the bladder has been reviewed elsewhere (Nathan 1976; Fletcher and

### Normal Urethral Function

The normal urethral closure mechanism maintains a positive urethral closure pressure
during bladder filling, even in the presence of increased abdominal pressure. Continence
can be seen to be maintained at the bladder neck in normal persons. This can be regarded
as the proximal urethral closure mechanism. If the vesico-urethral junction (bladder neck)
is incompetent, then continence may still be maintained at the high-pressure zone in the
urethra, approximately 2 cm to 3 cm distally. This zone corresponds to the maximum
condensation of muscle, both smooth and striated, and may be regarded as the distal
urethral closure mechanism. Whether it is really valid to separate two parts of the urethra
in this way from the physiological point of view is debatable; the normal urethra probably
works as one unit. However from a practical standpoint it is useful because the urethral
areas may not be abnormal simultaneously.

Many factors have been thought to contribute to urethral closure; some are obvious,
others less so. They are:

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**Fig. 2.3** Simplified representation of the cerebral areas involved in micturition. The multiplicity of inter-
actions makes it easy to appreciate why the subject should be left to the research physiologist. +, facilita-
tion; –, inhibition; ac, anterior cingulate gyrus; am, amygdala; pl, paracentral lobule; po, preoptic
nucleus; rf, pontine reticular formation; sc, subcallosal cingulate gyrus; se, septal area; sfg, superior
frontal gyrus. (Torrens 1982)
Muscular occlusion by the intraurethral striated muscle.
- Transmission of abdominal pressure to the proximal urethra.
- Mucosal surface tension.
- Anatomical configuration at the bladder neck, including support from the endopelvic fascia and the pelvic floor muscles.
- Submucosal softness and vascularity.
- Inherent elasticity, particularly at the bladder neck.
- Urethral length.

While the relative importance of these various factors remains unknown, it is better to consider and describe only those that can be observed objectively: urethral closure pressure, electromyography (EMG) and videoscopic appearance of the urethra. Mechanical and hydrodynamic analogues, such as those quoted by Zinner et al. (1976), serve only to demonstrate how complicated the situation is. However the work of Delancey (1990) has helped us to understand the way in which the endopelvic fascia consisting of fascial sheets and condensations of fascia, around the urethra and bladder neck, are important in normal function. The attachments of the vagina to the pelvic floor provide a hammock under the proximal urethra and bladder base against which the bladder neck can be compressed when intra-abdominal pressure rises.

Typically urethral closure pressure decreases at or before the onset of micturition and is synchronous with bladder base descent seen by imaging and with the reduction of EMG activity from striated muscle of the intraurethral sphincter of the urethra, the pelvic floor or the external anal sphincter (Fig. 2.4, overleaf). It is a fallacy to consider that the urethra is forced open by a head of detrusor pressure. Micturition usually occurs at a voiding pressure less than the maximum resting intraurethral pressure; the decrease in urethral closure pressure represents an active relaxation process. Part of the pressure decrease can be attributed to the relaxation of the striated muscle of the pelvic floor, but part seems to be the result of active inhibition of the intraurethral striated sphincter. This can be reproduced by stimulation of the sacral nerves, especially S4 (Torrens 1978). Many women appear to void by relaxation and urethral opening only, no detrusor pressure rise being necessary. Undoubtedly urethral resistance in women is low, and the inner longitudinal smooth muscle may help reduce resistance by contracting and thereby making the urethra shorter and wider, thus facilitating micturition.

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**Fig. 2.4** Intravesical (B) and urethral (U) pressure and striated sphincter EMG (E) during volitional voiding. At the initiation of voiding (1), the urethral pressure falls to a minimum before the intravesical pressure starts to rise. Flow is initiated at (2), before an appreciable intravesical pressure has been generated. Flow is therefore a consequence of urethral relaxation in this female subject. At cessation of flow EMG activity returns after a period of silence, and the urethral pressure transiently rises while the proximal urethra is emptied back into the bladder. (McGuire 1978)
Detrusor Function

The urinary bladder is not a sphere even when contracting, and calculations of tension based on that premise must be to some extent erroneous. Its shape is more that of a three-sided pyramid, base posterior and apex at the urachus. The superior surface is covered by peritoneum and is pressed upon by the other viscera. The two inferior surfaces are supported by the pelvic floor and connected to the pelvic fascia by various condensations of fibroareolar tissue. Also important are the condensations of the endopelvic fascia, sometimes known as the “pubourethral ligaments”. The functional adequacy of the bladder does depend on its correct anatomical position, so heavy viscera or inadequate pelvic support cause functional problems such as incontinence and prolapse. The detrusor is composed of an interlacing network of smooth muscle bundles. These are not layered, as has sometimes been described and as is the case in the intestine. It is not clear whether the detrusor around the bladder neck is involved in the mechanisms of closure and opening of the bladder neck, and the various mechanical theories of function that have been elaborated are presumptive and should be interpreted with great caution.

The golf enthusiast will readily understand the muscle fibre arrangement of the detrusor because it is similar to the structure of a golfball beneath its white coating. The muscle fibres run in all directions and change depth in the bladder wall. The detrusor muscle is relatively rich in acetylcholinesterase. As discussed, this is evidence for a dominant cholinergic innervation and very little noradrenergic activity can be demonstrated histochemically.

Innervation

Efferent motor nerves to the detrusor arise from the parasympathetic (cholinergic) ganglion cells in the pelvic plexus. The preganglionic fibres run in the sacral roots 2 to 4 within the pelvic nerves. The third root is the dominant nerve in most cases. The parasympathetic supply is excitatory. Preganglionic parasympathetic fibres and post-ganglionic sympathetic fibres both synapse with ganglion cells close to and within the bladder wall: it is believed that the sympathetic fibres act to inhibit the parasympathetic before being “switched off” at the onset of micturition.

Nerve-mediated detrusor inhibition has been described, occurring after stimulation of the pelvic floor or perianal area, and may be the mechanism by which some methods of nerve stimulation are effective in treating detrusor overactivity. Such inhibition may be mediated by the sympathetic nervous system (Sundin and Dahlstrom 1973). Bladder relaxation evoked by bladder wall stretch (accommodation) may be similarly mediated. Gosling (1979) has shown that little significant sympathetic innervation reaches the bladder dome in humans. As a result, it is suggested that inhibition occurs at the neurones in the pelvic ganglia where noradrenergic axosomatic terminals have been observed. The sympathetic supply to the pelvic ganglia arises at the T10 to T12 level and runs in the presacral nerves and hypogastric plexus. The muscle around the bladder neck in both sexes is similar to that of the rest of the bladder. Most nerve terminals are acetylcholinesterase-positive and almost no noradrenergic terminals are seen. (This is in contradistinction to certain species of animals.)

The sensory nerves from the bladder run with the motor supply. In general, the proprioceptive afferents related to tension enter the sacral segments, as do the greater proportion of enteroreceptive afferents related to pain and temperature. Poorly localised sensations of pain and distension enter with the sympathetic fibres at a high level. The innervation of the bladder and urethra is summarised in Fig. 2.5.
Fig. 2.5 Summary of the possible organisation of the peripheral nervous supply to the lower urinary tract. Preganglionic parasympathetic fibres and postganglionic sympathetic fibres both synapse with ganglion cells close to, and within, the bladder wall. The arrangement in relation to the urethra may be morphologically similar but functionally different. The periurethral striated muscle (pelvic floor) is supplied by the pudendal nerve. The somatic nerve supply to the intramural urethral striated muscle runs with the pelvic nerve and is vulnerable during pelvic surgery. (Torrens 1982)

References


Chapter 3

Urodynamic Techniques

Introduction

The evolution of urodynamic units may be traced to the interest in the hydrodynamics of micturition which had been simmering since the early cystometric studies of the nineteenth century, but it was the advent of electronics that acted as the catalyst for modern urodynamic studies. In 1956 von Garrelts described a simple practical apparatus, using a pressure transducer, to record the volume of urine voided as a function of time. By derivation, urine flow rates could be calculated. His work stimulated a revival of interest in cystometry because it was then possible to record the bladder pressure and the urine flow rate simultaneously during voiding. As a result, normal and obstructed micturition could be defined in terms of these measurements (Claridge 1966), and a formula was applied to express urethral resistance (Smith 1968). Enhorning (1961) measured bladder and urethral pressures simultaneously with a specially designed catheter, and he termed the pressure difference between them the "urethral closure pressure". He demonstrated that a reduction of intraurethral pressure occurred several seconds prior to detrusor contraction at the initiation of voiding. This appeared to be related to the relaxation of the pelvic floor, thus confirming the EMG studies of Franksson and Peterson (1955).

These original research studies led rapidly to the application of urodynamic investigations in the clinical field. Radiological studies of the lower urinary tract, using the image intensifier and cine or videotape recordings, were already established, and their value in the assessment of micturition disorders had been described (Turner Warwick and Whiteside 1970). Thus it was a relatively simple step to combine cystourethrography with pressure flow measurements (Bates et al. 1970) Later, more sophisticated techniques, using EMG recordings of the pelvic floor, were employed, particularly for neurogenic bladder problems (Thomas et al. 1975). These clinical studies during the 1970s emphasised the need to investigate the function as well as the anatomical structure of the lower urinary tract, when evaluating micturition disorders. Urodynamics was established as a necessary service commitment, rather than a research tool.
Simulaneous with these technical developments was an increasing awareness of the clinical problem of urinary incontinence. Caldwell (1967), working in Exeter, initiated considerable interest in the subject because he approached the treatment of incontinent patients with electronic implants. In his sphincter research unit, a small receiver was developed that could be placed subcutaneously in the abdominal wall and activated by a small external radio-frequency transmitter. Platinum iridium electrodes led down to the pelvic floor muscles, which could be stimulated. Other new techniques advocated at this time included pelvic floor faradism applied under general anaesthetic (Moore and Schofield 1967) and a variety of external electronic devices which could be placed in the anal canal or vagina to stimulate pelvic floor contraction (Hopkinson and Lightwood 1967; Alexander and Rowan 1968).

Through the 1980s and 1990s the principles of urodynamics remained unchanged. As microchip technology has advanced, so urodynamic equipment has become computerised, although this has not always been for the best, as discussed later. New techniques became available, such as the measurement of bladder neck electrical conductance, a technique devised by Plevnik. Computerisation has allowed the development of more complex and sophisticated neurological investigations, such as cortical evoked responses, although these techniques are used only in specialist centres. James introduced long-term (ambulatory) techniques to study bladder and urethral function. His work became the focus of increased attention in the early 1990s, and, with computerisation, the patient has been set free from the fixed urodynamic recording apparatus. Ambulatory studies, which represent a more physiological approach, have become established as a secondary method of investigation in more specialist units.

This chapter discusses the technical aspects of urodynamics. The indications of urodynamics are mentioned here only briefly, as their clinical role is discussed fully in Chapter 5.

**Principles of Urodynamic Technique**

Investigations must be carried out in a safe and scientific manner. The investigator is responsible for ensuring the privacy and comfort of the patient. Micturition is a private matter, and unless this is respected, urodynamics will be less than satisfactory. Proper care must be applied to the infection control aspects of investigation and the principles of sterility followed.

The investigations themselves must be free of technical errors, and, just as the grand prix driver must be familiar with the mechanics of his car, the urodynamicist must be familiar with the technical aspects of the tests they are using. This applies particularly to the measurement of pressure. The investigator must also be satisfied as to the reproducibility of urodynamic results, so that at the end of the investigation the patient can be offered explanations for his or her symptoms and the clinician can be given advice as to how the patient should be managed.

**Standardisation of Techniques**

Both technique and terminology should be standardised. Of course, techniques must evolve, but not on an unplanned basis. Each department’s individual technique should be standard
to allow for interpretation of findings. So that others may understand and interpret the results from any urodynamic unit, standardised terminology to describe the technique and the results obtained is essential. To facilitate this, the International Continence Society in 1973 set up a standardisation committee, which has produced reports on the terminology of lower urinary tract function (Appendix 1, Part I). The first six reports were collated in 1988 and comprehensively rewritten in 2002. The subjects covered include:

- Procedures related to the evaluation of urine storage.
- Procedures related to the evaluation of micturition.
- Procedures related to the neurological investigations of the urinary tract during filling and voiding.
- A classification of lower urinary tract dysfunction.
- Pelvic floor and pelvic organ prolapse assessment
- Ambulatory urodynamics
- Pressure-flow studies of voiding, urethral resistance and urethral obstruction.
- Good urodynamic practices.

These standards are proposed to facilitate comparison of results by investigators who use urodynamic methods. It has been recommended that written publications acknowledge the use of these standards with a footnote stating: "Methods, definitions and units conform to the standards proposed by the International Continence Society except where specifically noted." The author has accepted these standards and used them in this book. They are repeated and explained in the relevant chapters; the reports are listed and published in full in Appendix 1.

This chapter forms the core of the book. Urodynamic studies are described at three levels: uroflowmetry, basic urodynamics (inflow cystometry, pressure-flow studies and pad testing) and complex urodynamics (urethral pressure profilometry, videourodynamics, ambulatory studies and various aspects of neurophysiological testing).

References

Uroflowmetry

Urine flow studies are the simplest of urodynamic techniques, because they are noninvasive and the necessary equipment is simple and relatively inexpensive. Before reliable recording apparatus was commercially available, some clinicians made a habit of watching the patient void. Any such semi-objective observation is valuable. However, for any flow rate assessment to be meaningful, the bladder should be reasonably full, an uncommon event in the outpatient clinic. In addition, the patient may find it embarrassing to have the voiding observed. Further, in most circumstances, it is not practical in women. The advantage of modern urine flowmeters is that a permanent graphic recording is obtained. Flowmeters had been available for many years, but not until von Garrelts developed his flowmeter in 1956 was equipment sufficiently accurate for the recordings to be clinically useful. If, despite the availability of commercially produced apparatus, the clinician has no flowmeter, the patient can be asked to time his urinary stream with a stopwatch and to record the voided volume by calculating the average flow. In the normal patient, average flow is approximately half the maximum flow, although in patients with bladder outlet obstruction the average flow may almost equal the maximum flow. We found it impractical to obtain adequate urine flow measurements in the routine urological clinic and therefore established the urine flow clinic (see later).

Definitions

Urine flow may be described in terms of flow rate and flow pattern, and may be continuous or intermittent.

- **Flow rate** is the volume of fluid expelled via the urethra per unit time and is expressed in millitres per second (ml/s). The basic information necessary in interpreting the flow trace includes the volume voided, the environment in which the patient passed urine and the position, that is lying, sitting or standing. It should also be stated whether the bladder filled naturally or if diuresis was stimulated by fluid or diuretics, or whether the bladder was filled by a catheter (either urethral or suprapubic). If filling was by a catheter, then the type of fluid used should be stated, as should whether the flow study was part of another investigation (e.g. a pressure-flow study).
- **Maximum flow rate** ($Q_{\text{max}}$) is the maximum measured value of the flow rate.
- **Voided volume** ($VV$) is the total volume expelled via the urethra.
- **Flow time** is the time over which measurable flow occurs (Fig. 3.1).
- **Average flow rate** ($Q_{\text{ave}}$) is voided volume divided by flow time.
- **Time to maximum flow** is the elapsed time from onset of flow to maximum flow.
- **Intermittent flow** The same measurements are used as for describing a continuous flow curve. However, flow time must be measured carefully, as the time intervals between flow episodes are disregarded. Voiding time is the total duration of micturition, including the interruptions (Fig. 3.2). Where flow is continuous, voiding time is equal to flow time. The area beneath the curve or curves represents the volume voided.
Urine flow studies should be performed in privacy when the patient has a normal desire to void and is relaxed. In our experience, it is difficult to get an adequate flow study in the routine outpatient clinic, as it is essential that the bladder is adequately full. Furthermore, a sterile urine sample is often required for bacteriology, necessitating a second void.

To facilitate good-quality flow studies, we established a flow clinic in 1981. Following this, Carter showed that the proportion of patients who failed to void 150 ml fell from 59% to 21%. The principal objective of the urine flow clinic is to screen for bladder outlet obstruction. With a flow clinic appointment, each patient is sent a seven-day frequency–volume chart to complete before the appointment. Patients are also asked to drink normally before they leave home on the day of their appointments. On arrival, the clinic nurse checks that

Fig. 3.1 Terminology relating to the description of urinary flow (International Continence Society report (1988) Standardisation of terminology of lower urinary tract function; see Appendix 1, Part 2).

Fig. 3.2 Terminology relating to an intermittent flow rate tracing (see Appendix 1, Part 2).

**Urine Flow Clinic**

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