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Urodynamic equipment: technical aspects

Produced by the International Continence Society* Working Party on Urodynamic Equipment

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Introduction

The two parameters that are most commonly measured in urodynamic studies are pressure and urinary flow rate. In each case a *transducer* is used to produce an electrical signal to represent these parameters in a form that can be readily recorded on chart paper or magnetic tape, displayed on an oscilloscope or stored digitally in a computer. Another useful parameter, the *electromyogram* (EMG), is already in an electrical form. Generally it is desirable to reproduce these parameters as 'faithfully' as possible, without modifying the signal appearing at the source. This can usually be achieved by direct *amplification*. Often, however, more useful, and perhaps more readily interpretable, data can be acquired by modifying the original signal before it is eventually displayed. This, together with amplification, is referred to as *signal processing*. Interference from other physiological variables may be present in the recorded signal, appearing as if originating from the source. The recorded signals should therefore be interpreted with caution.

Signal processors

A typical electronic system used for measuring urodynamic parameters is shown in figure 1, the design procedure taking into account the importance of maintaining compatibility between the various components in the overall system. Processors can be used to:

(1) Amplify the signal.
(2) Filter the signal.
(3) Differentiate the signal.
(4) Integrate the signal.
(5) Convert the analogue signal into digital form.

Amplification

The ideal amplifier changes the amplitude of an applied signal without distortion.

Signal filtration

Signals which change their values with respect to time can be described as the sum of a number of components of different frequencies possessing different amplitudes. More rapidly changing signals contain higher frequencies. As examples, the changes that occur in bladder pressure on coughing are much more rapid compared to the slower changes that occur during detrusor activity. Other frequencies, perhaps even higher than those encountered physiologically, may also appear superimposed on the signal in the form of 'noise'. By limiting the frequency range of the measuring system, it is possible to reproduce signals which can adequately represent the parameter being measured, whilst at the same time filtering out the noise. To reproduce the rapidly changing signals quoted above, an amplifier with a frequency range of DC—15 Hz is required; however, for EMG measurements, this would have to be extended to several kilohertz (kHz).

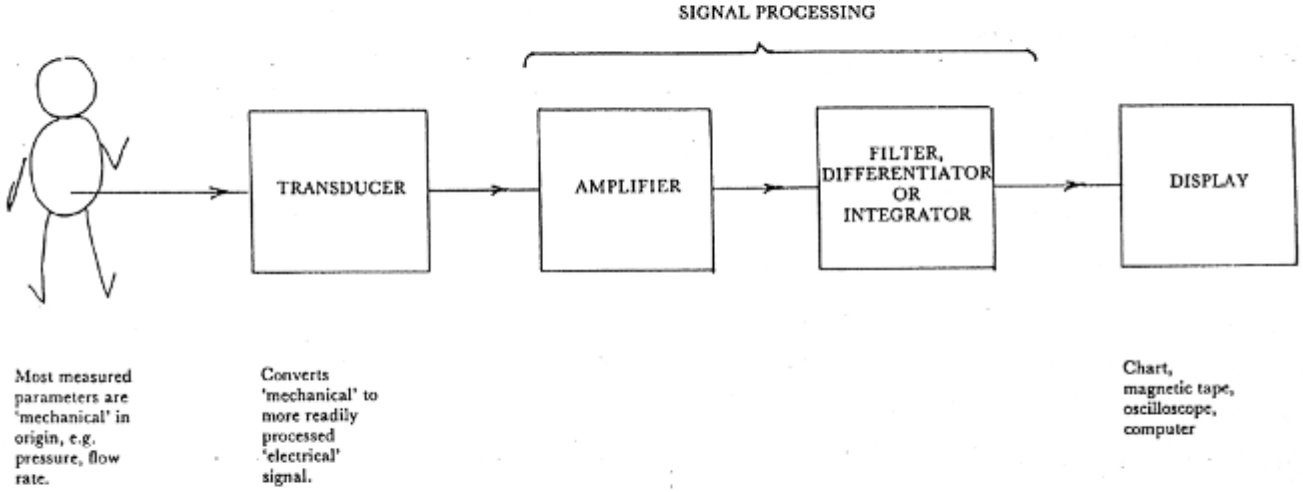

Figure 1. Typical 'system' for measuring physiological parameters.

* See note on Society on p. 64.

The principle of filtering can be illustrated by reference to recordings obtained from urine flow rate meters which measure the rate at which urine is collected in an external vessel. Inevitably *mechanical noise* is introduced during this measurement, which subsequently appears as electrical noise Without adequate filtering the recorded signal could be difficult to interpret (figure 2). Excessive filtering not only reduces the noise further but also prevents the important components of the signal from being recorded. The marked effects of different filters on pressure recordings are shown in figure 3.

Differentiation

Often the rate of change of a signal with respect to time contains more useful information than the original signal. This information can be derived from the original signal by the process of *differentiation*. The most frequently encountered application of differentiation occurs in flow rate meters that measure the volume or mass of urine (figure 4[*a*]). Following differentiation (figure 4[*b*]), the signal represents the volumetric or mass flow rate (see section on 'Flowmeters', page 60).

Integration

Integration, the reverse process of differentiation, is used to produce a signal to represent the area under a curve. For example, the area under the curve (figure 4[*b*]) of a direct recording of urine flow rate (see section on 'Flowmeters', page 60) is equivalent to the total voided volume (figure 4[*a*]).

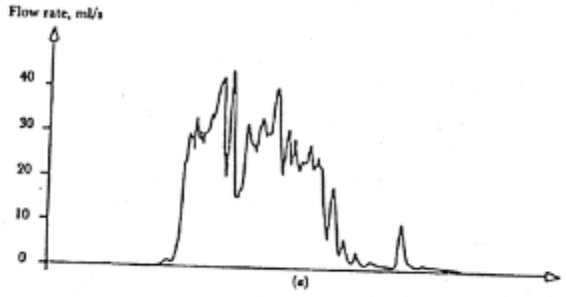

Figure 2(a). Flow rate recording, including mechanically-generated and 'other' noise.

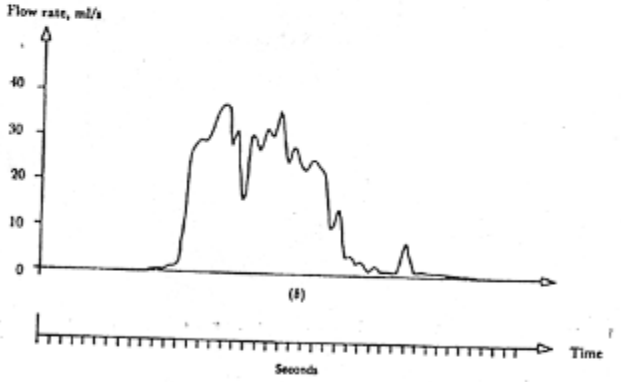

Figure 2(b). Following filtering the flow rate recording still contains adequate diagnostic data.

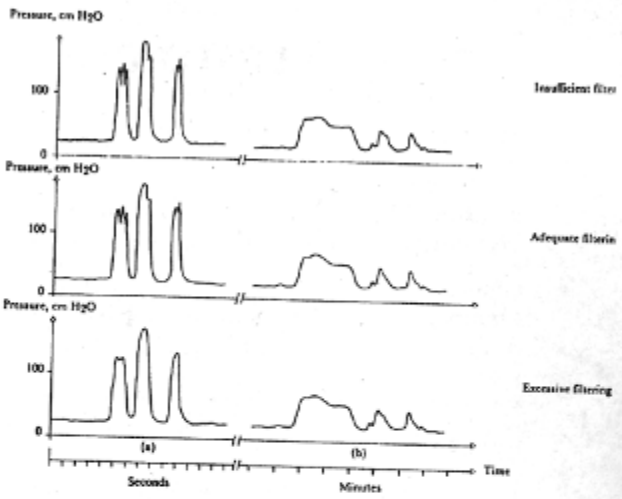

Figure 3. Coughs (rapid pressure changes) and detrusor spasm (slow pressure changes).

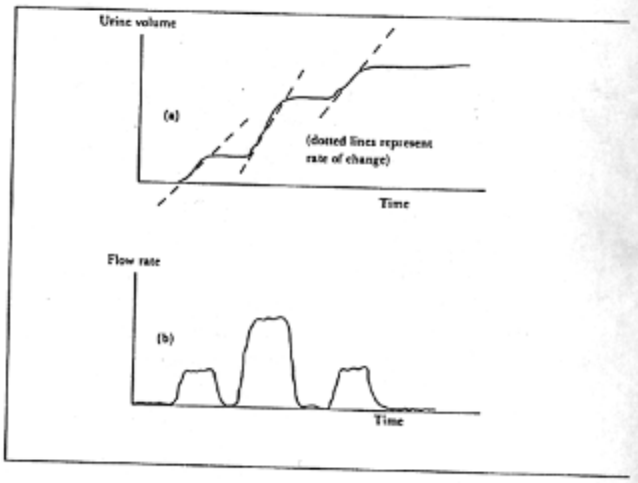

Figure 4. Differentiation: the original signal (a) representing the volume (or mass) of urine when differentiated appears as the flow rate signal (b).
Integration: the original signal, now (b), when integrated represents the volume (or mass) of urine voided (a).

Integrating techniques also find useful application in the processing of EMG signals. In common with differentiators, integrators have characteristics which define the range over which they can be operated.

Analogue-to-digital conversion

Signals representing urodynamic parameters normally appear in a continuous uninterrupted form (analogue). The signals can also be approximated by a series of discrete numbers (digital). It is often useful to convert analogue signals into digital form for direct presentation of numerical data such as 'the volume of urine voided' or for feeding into a computer for further processing or analysis.

power required to keep the disc rotating at a constant rate is measured and is proportional to the mass flow rate of the fluid. The accumulated mass is obtained by integration.

Many other metering techniques are known including electromagnetic, ultrasonic, radioisotope and drop spectrometry. However, these are not in general use.

Characteristics of flowmeters

Static characteristics

The most important static characteristic of a flowmeter is its accuracy over its usable range.

Zero offset: zero offset is the non-zero output signal of a flowmeter at zero input flow.

Linearity and hysteresis: the output signal of a flowmeter system should ideally be proportional to the input flow. In practice non-linearity and hysteresis errors are encountered similar to those described in the section on Pressure transducers.

Accuracy: the offset should be set to zero and the sensitivity control adjusted during the calibration procedure. The accuracy will then be determined by the non-linearity and hysteresis.

It is common for manufacturers to state system accuracy only in terms of percentage full-scale error which can be readily misinterpreted (see section on Accuracy).

Dynamic characteristics

Time constant (τ) is a measure of the frequency response of a system. It is defined as the time required for a system to register 63% of its final reading when subjected to a step change in input (figure 5). The larger the time constant, the lower the frequency response.

The time constant is increased by filtering, which can be introduced into the system mechanically or electronically. Mechanical filtering occurs primarily at the funnel. The degree of filtering is influenced by funnel design, by the location and angle at which the stream strikes the funnel and by the flow rate. The filtering effect of the funnel cannot be calculated *a priori;* it must be determined experimentally. Electronic filtering is designed into the system to reduce signal noise. The time constant of the electronics should be stated by the system manufacturer.

Use of flowmeter in pressure-flow studies

In many investigations urinary flow rate is measured in conjunction with bladder pressure. If the pressure events in the bladder are to be correlated with variations in the flow rate, the *dead time* between the pressure event and the flow event must be estimated.

Dead time (θ) is the delay between the exit of the urine from the bladder and its initial registration by the flowmeter (figure 5).

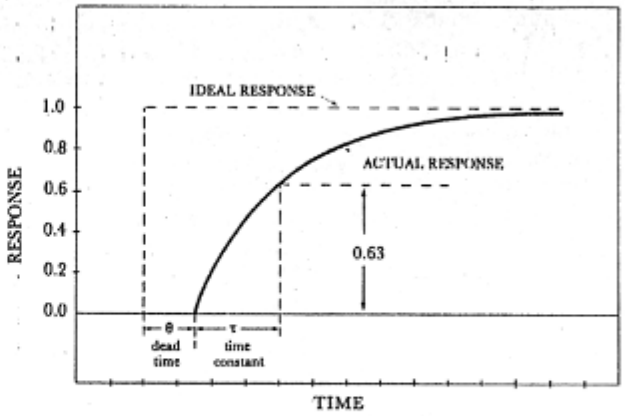

Figure 5. Typical dynamic response of a flow meter system to a unit step change in input flow.

Several factors contribute to the dead time:

(1) The time taken for urine to traverse the urethra.

(2) The time taken for urine to pass from the external meatus to the flowmeter funnel.

(3) The time taken for urine to pass via the funnel to the transducer.

System specifications

Range

A meter with a flow rate range of 0–50 ml/s and a volume range of 0–1000 ml is adequate for clinical use. These ranges will be exceeded only in exceptional cases.

Time constant

The time constant should be as short as possible. For most flowmeters on the market a time constant of 0·75s is needed to achieve a reasonable compromise between noise reduction and loss of meaningful temporal information. This time constant should include the contribution of both the funnel and the electronics.

Accuracy

For clinical purposes the measured and indicated flow rate should be accurate to within ± 5% over the clinically significant flow rate range. It is therefore recommended that the calibration curve representing the percentage error over the entire range is made available.

The use of percentage full-scale error should be avoided as this can be misinterpreted. For example, a flowmeter with a range of 50 ml/s and a quoted accuracy of ± 5% full-scale error could have a maximum absolute error of 2·5 ml/s. If this error occurred at a flow rate of 10 ml/s, the percentage error in the measured flow rate would be 25%.

EMG measurements

Electromyography (EMG) is the recording of the electrical activity of contracting muscles and so no transducers are required. The electrical signals, however, are

chambers filled with similar fluids, the greater the volume displacement for a given applied pressure, the lower the frequency response.

Frequency response

The response of most modern transducers used for physiological purposes is more than adequate when pressure measurements are made at source. However, if the pressure to be measured is transmitted to the transducer via a liquid-filled catheter, then the dynamic characteristics of the system are limited by the dimensions and compliance of the catheter and its connections. Thus the frequency response decreases as the internal diameter of the catheter decreases and as the length and the compliance of the coupling system increase. Since air is compressible, all air bubbles must be removed from the liquid coupling otherwise the response will be dampened. The response of a particular system can be measured by coupling it to:

(1) A hydraulic sinusoidal pressure generator of variable frequency; or

(2) A chamber in which the pressure can be very rapidly changed (step response).

The response required depends on the type of investigation. For example in filling cystometry, a frequency response of typically DC–4 Hz is adequate. On the other hand, when rapid changes of pressure, which occur on coughing or during patient movement, are to be studied, a frequency response of typically DC–15 Hz is desirable.

Complete pressure measuring system

When transducers are incorporated in complete pressure measuring and display systems, further detrimental effects may be introduced. The effect on the frequency response and any additional drifts introduced by the chart recorder must be specified by the manufacturer.

Flowmeters: characteristics and specifications

In urodynamic investigations a flowmeter is a device that measures and indicates the quantity of fluid (volume or mass) passed per unit time. Depending on the type of transducer used, either the *flow rate* or the *instantaneous accumulated amount* can be measured. Uroflowmeters normally indicate the *volumetric flow rate*.

Units of measurement

The SI unit for volumetric flow rate is the cubic metre per second (m^3/s) and for mass flow rate is the kilogram per second (kg/s). However, the millilitre (ml) is also an acceptable unit [1], and it is conventional in urodynamic work [2] to report volumetric flow rate in millilitres per second (ml/s). The unit cubic centimetre per second (cm^3/s) should not be used.

Conversion of units

The volumetric flow rate and the accumulated volume are related as follows:

Volumetric flow rate
Q = rate of change of accumulated volume (V) with respect to time, i.e. $Q = dV/dt$.

Similarly, accumulated volume
V = integral of the volumetric flow rate (Q) with respect to time, i.e. $V = \int^t Q\,dt$.

Conversion between flow rate and accumulated volume is usually done electronically.

The mass and volume of fluid are related as follows:

$$m = \rho V$$

where m = mass of fluid
ρ = density of fluid
V = volume of fluid.

The conversion between mass and volume (or between mass flow rate and volumetric flow rate) can only be carried out provided the fluid density is known.

If a particular flowmeter measures the *accumulated mass of fluid*, the volumetric flow rate is obtained from:

Volumetric flow rate
Q = rate of change of accumulated mass (m) with respect to time divided by the density (ρ)

$$\text{i.e. } Q = \frac{1}{\rho}\frac{dm}{dt}.$$

The *mass flow rate* is obtained by electronic differentiation. The volumetric flow rate is obtained by dividing the mass flow rate by the fluid density.

Normally mass flowmeters are calibrated for water. When other liquids are used with densities significantly different from water, in particular a radio-opaque medium, the instrument must be recalibrated.

Types of transducer

The most commonly used uroflowmeters employ one of the following methods.

Gravimetric method: these instruments operate by measuring the weight of the collected fluid or by measuring the hydrostatic pressure at the base of the collecting cylinder. In either case, the output signal is proportional to the mass of fluid collected. Gravimetric meters therefore measure accumulated mass and mass flow rate is obtained by differentiation.

Electronic dip stick method: in this method the electrical capacitance of a dip stick mounted in the collecting chamber changes as the urine accumulates. The output signal is proportional to the accumulated volume and the volumetric flow rate is obtained by differentiation.

Rotating disc method: the voided fluid is directed on to a rotating disc increasing the inertia of the disc. The

Pressure transducers: characteristics and specifications

A *pressure transducer* is a device that converts an applied pressure into an electrical signal, the magnitude of which is proportional to the pressure. The pressure to be measured, for example that within the bladder, may be transmitted to an external transducer using either an open-ended or sealed, liquid or gas-filled, catheter. Alternatively, the pressure may be measured by a small transducer mounted directly on the catheter. There are four principal types of transducer: resistive (strain gauge), capacitive, inductive and opto-electronic.

Units of measurement

The SI unit of pressure is the pascal (Pa) although in urodynamics the unit cm H_2O (1 cm H_2O = 98·07 Pa) is still used. When parameters that are a function of pressure, for example compliance, are calculated, SI units must be used [2].

Important characteristics and specifications of pressure transducers

Pressure range

A pressure range of 0–300 cm H_2O (0–30 kPa) is adequate for pressure measurements in the urinary tract and in many cases a range of 0–200 cm H_2O (0–20 kPa) is acceptable (for example in the measurement of intravesical pressure).

Sensitivity

The sensitivity of a transducer is defined as the change in amplitude of its output signal per unit change in applied pressure. A change in sensitivity with temperature is called *sensitivity drift*. A drift of less than 0·1%/°C is desirable.

Linearity and hysteresis

In an ideal transducer the electrical output is linearly related to the applied pressure. Non-linearity is specified as a percentage of the pressure range. In addition the output signal has a slightly different value for a given applied pressure depending on whether this is increasing or decreasing in amplitude. This effect is called *hysteresis*. It is common practice to give a combined figure for linearity and hysteresis in terms of a specified percentage deviation over a stated pressure range. A value of not more than ± 1% over the range 0–100 cm H_2O (0–10 kPa) is acceptable.

Overload pressure

Transducers can be permanently damaged by applying excess pressure. The maximum pressure that may be applied without affecting the transducer characteristics is called the *overload pressure*. Typical values are in the range 1500–5000 cm H_2O (150–500 kPa). The calibration over the working range should change by less than 1% after the overload pressure is removed.

A pressure above a certain level will destroy a transducer; this is defined as the *damage pressure level*.

Note: In practice it is very easy to exceed the maximum rated pressure if the transducer chamber is flushed out with a high resistance in the outlet (for example a fine bore catheter or a closed tap).

Zero offset

All transducers have a small electrical signal output when the applied pressure is atmospheric (or zero in the present context); this is known as the *zero offset signal*. Provided this offset is constant, no errors in measurement will be introduced since the transducer signal conditioner can be adjusted to produce a zero output. The change in the offset signal with temperature, called *zero offset drift*, is more important than the absolute value. A zero offset drift of less than 0·1 cm H_2O/°C (10 Pa/°C) is desirable.

Zero reference level

A transducer is normally calibrated against atmospheric pressure. In urodynamics the zero reference level is taken as the superior edge of the symphysis pubis [2]. When a liquid-coupled system is used to measure pressure within the bladder, the transducer is subjected to two sources of hydrostatic pressure which tend to cancel:

(1) The pressure arising from the presence of liquid in the catheter.
(2) The pressure due to the depth of the catheter tip within the volume of urine.

With this type of system, therefore, the measurement of bladder pressure is substantially independent of the location of the tip of the catheter within the bladder. On the other hand, the pressure measured by micro-tip and sealed gas systems is dependent on the position of the membrane within the bladder.

Detrusor pressure is calculated by electronic subtraction of the abdominal pressure from the intravesical pressure [2]. To achieve a good approximation to detrusor pressure, both abdominal and intravesical pressure should be measured with reference to the standardized zero level (superior edge of the symphysis pubis) using liquid-coupled external transducers. However, for studies involving significant patient movement (for example, ambulatory monitoring) a liquid-filled system is unsuitable as the zero reference may vary and major artefacts are produced due to movement of the liquid in the catheter. In these cases a qualitative assessment of detrusor pressure can be made using a micro-tip or sealed gas system.

Volume displacement

The pressure applied to a transducer produces a movement in its diaphragm. The volume change caused by a specified pressure is called the *volume displacement* of the transducer. Typical values are in the range 0·03 mm^3/100 cm H_2O–0·003 mm^3/100 cm H_2O (0·03 mm^3/10 kPa–0·003 mm^3/10 kPa). In general, for catheters and transducer

so minute that special amplifying techniques are needed. Consideration will be given only to the recording of EMG activity of striated muscles.

The functional contractile unit is the *motor unit*. Each motor unit while contracting has a *firing frequency* ranging from 10 to 100 discharges/s. Normal muscle activity results in the asynchronous contractions of many motor units, leading to an *interference pattern* in the EMG recording. This activity is detected by electrodes inserted into, or placed adjacent to, the muscle.

Electrodes

The electrical potential variations in muscle can be sensed either with respect to an unchanging reference value (*monopolar approach*) or as the potential difference between two points (*bipolar approach*) in or adjacent to the muscle.

Monopolar

The reference value, the potential level of the extracellular fluid, is sensed by an indifferent electrode. This electrode has a greater surface area than the active electrode and is placed remotely from it. The latter may be placed on the skin in the neighbourhood of the muscle (*surface electrode*) or in the bulk of the muscle (*tip electrode or coaxial needle electrode*). In the coaxial needle approach, the shaft of the needle acts as the indifferent electrode.

Bipolar

Bipolar surface electrodes are widely used in urodynamics; anal plug electrodes, urethral catheter electrodes and self-adhesive electrodes on the perineum are examples. The bipolar intramuscular approach (*bipolar wire electrodes*) is less popular than the use of the coaxial needle.

Types of recording

Bipolar wire and coaxial needle electrodes have sensing ranges of about 1 mm around the tip of the electrode. They register the sum of the activities of all muscle fibres within this range (*motor unit potentials*). In the sphincteric muscles bi- or triphasic potentials lasting about 7 ms are mostly recorded. The amplitudes of these potentials are dependent on the arrangement of the intermingled fibres from the various motor units with respect to the electrode. With increasing contraction the discharge frequency of individual motor units and the number of asynchronously activated motor units increase leading to a complex record of potential variation known as *interference pattern*. Parameters of this pattern are only qualitatively related to the contraction strength.

Surface electrodes register potential variations from the bulk of the muscle. These electrodes are suitable for assessing the overall behaviour of large muscles. Reflex responses, sphincter activity in relation to bladder conditions and the patient's ability to voluntarily control muscle can be checked adequately by this technique.

EMG amplification

Characteristics

To enable the EMG to be adequately displayed, an amplifier with a wide frequency range is required. The amplifier has also special characteristics to reduce signal distortion and electrical noise.

Specifications

A good-quality EMG amplifier should have the following specifications:

Input impedance:	Minimum of 100 megohms shunted by a maximum of 10 picofarads.
Common mode rejection ratio:	Greater than 1000 (80 dB)
Frequency range:	Flat characteristic from 10 Hz to 10 kHz
Voltage input range:	5 μV–50 mV
Overload recovery time:	Less than 100 ms
Output impedance:	50 ohms.

Artefacts

EMG recording is very sensitive to artefacts. These can be minimized by:

(1) Optimum positioning of electrodes and leads.
(2) Appropriate preparation of skin when surface electrodes are employed.
(3) Proper grounding of instrumentation and the use of an isolation amplifier for connection to the patient.

Processing of EMG signals

A variety of processing techniques are available to assist in the interpretation of EMG signals. Rectification and smoothing are often used to produce a low frequency signal which provides information on the timing and relative strength of muscle contraction.

Recording and display systems

Electrical signals corresponding to physiological parameters can be displayed directly or stored for subsequent examination. This can be achieved in a number of ways:

(1) By displaying on a screen of a cathode ray oscilloscope.
(2) By recording directly on to a paper chart recorder.
(3) By storing on magnetic tape.
(4) By digital storage.

Cathode ray oscilloscope

Because this device can faithfully reproduce signals with a high frequency range, it is often used to display rapidly changing physiological parameters (for example EMG). The displayed data can be photographed for permanency or stored for short periods of time (say minutes) using special *storage oscilloscopes*.

The cathode ray tube is also incorporated in Video Display Units (VDU) of computers and in image intensifying systems. In the latter a video mixing unit is employed to enable the registration of physiological parameters simultaneously on the same screen (video-pressure-flow-cystourethrography). The combined information can be stored on a *video tape recorder*.

Paper chart recorders

These are employed in urodynamic investigations to produce continuous visual displays of one or more parameters, in most cases with respect to time. The basic components are:

(1) An electromechanical device to convert an electrical input signal to mechanical movement.

(2) A writing mechanism to produce on paper a visual record of the mechanical movement (pen, ink-jet or light beam). Recordings may be written in curvilinear or rectilinear form. Depending on the type of recorder, the paper is driven at appropriate selected speeds or held stationary as the writing mechanism operates. The parameters may be recorded with respect to time (X-t recorders) or with respect to one another (X-Y recorders/plotters).

The frequency response of a recorder is particularly important for accurate reproduction of the signal. The following features must be taken into account when selecting a recorder:

(*a*) Number of channels.

(*b*) Type of paper, writing principle and recording format.

(*c*) Input sensitivity and offset adjustment.

(*d*) Chart speed.

(*e*) Time and event markers.

(*f*) Writing span.

(*g*) Trace accuracy.

(*h*) Start-stop on front panel or by remote control.

(*i*) Power supply (a.c. or d.c.).

Most urodynamic signals are unlikely to contain frequency components greater than 15 Hz and can be recorded on almost any of the instruments described. For direct EMG recording, however, pen-type recorders are inadequate.

Magnetic tape recorders

Signals are stored on magnetic tape for subsequent display, processing and analysis. Only *instrumentation tape recorders* should be used.

Magnetic tape recording techniques

Two recording techniques are employed for analogue recording, the most important being *frequency modulation* (FM) and the other the *direct mode*. The former is capable of recording signals with frequency components ranging from DC to several kilohertz. The direct mode covers the frequency range of, typically, 10 Hz–100 kHz.

In urodynamics the FM mode must be used for recording all parameters with the exception of raw EMG signals. These signals are best recorded using the direct mode.

To select a suitable instrumentation tape recorder the following features should be considered:

(1) Tape speed range.

(2) Flutter (tape speed stability) and flutter compensation.

(3) Maximum input signal.

(4) Signal-to-noise ratio.

(5) Number of signal and voice channels.

Digital storage

The discrete data obtained when analogue signals are converted to digital form can be stored as follows:

(1) On magnetic tape using the technique of *Pulse Code Modulation* (PCM).

(2) Via a computer on to floppy disk, hard disk or non-volatile *Random Access Memory* (RAM). These techniques are known as data acquisition.

Electrical safety aspects

Any electrical equipment used in urodynamic investigations in common with all other medical instrumentation should comply with the recommendations of the International Electrotechnical Commission [3]. Prospective users of such equipment should seek advice from a suitably qualified engineer or physicist.

References

1. *The International System of Units* (1973) Her Majesty's Stationery Office, London.
2. Bates, P., Bradley, W. E., Glen, E., Griffiths, D., Melchior, H., Rowan, D., Sterling, A., Zinner, N. and Hald, T. (1979) The standardisation of terminology of lower urinary tract function. *Journal of Urology*, **121**, 551–554.
3. International Electrotechnical Commission (1977) *Safety of Medical Electrical Equipment. Part I. General Requirements* (IEC 601–1, Geneva).

THE INTERNATIONAL CONTINENCE SOCIETY

The International Continence Society has over 900 members from 39 different countries and includes physicians, surgeons, nurses, physicists, bioengineers and other scientists. Its primary interest is to study disorders of the lower urinary tract, particularly incontinence, its diagnosis and management and to encourage research into diagnostic techniques and treatment.

Over the last 20–25 years, co-operation between physicists, bioengineers and clinicians has led to the development of sensitive electronic instrumentation with an adequate dynamic response for the objective study of the pressure and/or flow characteristics of the lower urinary tract. This, in turn, has led to a rapid expansion of techniques for the evaluation of all types of incontinence and to the establishment of urodynamic clinics in a large number of hospitals, particularly in Europe, North America and Japan.

With the increasing number of clinicians performing these investigations, it became apparent that there was a need for the Society to provide guidance on the function and limitations of the available measuring equipment. This task was given to a small Working Party of physicists and bioengineers. In 1984 a draft report was presented to the ICS Annual Meeting in Innsbruck. Following comments from members and further discussion within the Working Party, the report was revised and finally approved by the Society in London in September 1985.

MEDICAL PHYSICS '87

To be held at the Innsbruck Congress Center and the University of Innsbruck, Medical Physics '87 (*9–12 September*) is sponsored by the Deutsche Gesellschaft für Medizinische Physik, the Österreichische Gesellschaft für Medizinische Physik and the European Federation of Organizations of Medical Physics.

Languages will be German and English and topics include:

Radiation therapy
Nuclear medicine
Quality control in diagnostic radiology, nuclear medicine and radiation therapy
Digital image processing
Impact of Cernobyl on medical physics
Dosimetry of internally deposited radionuclides
Medical applications and safety of non-ionizing radiations
Magnetic resonance techniques
Hyperthermia
Whole body irradiation.

In addition to scientific sessions there will be a commercial exhibition.

Details from Professor Dr H. Bergmann, Division of Nuclear Medicine, 2nd Medical Department, University of Vienna, Garnisongasse 13, A-1090 Vienna, Austria. Tel. No. (+43) 222-4800, Ext. 2142, 2187, 2317.

EUROSENSORS: THIRD CONFERENCE ON SENSORS AND THEIR APPLICATIONS

Cavendish Laboratory, Cambridge, UK—22–24 September 1987

Organized by The Institute of Physics, 47 Belgrave Square, London SW1X 8QX; and co-sponsored by The Institute of Measurement and Control, The Institution of Electronic and Radio Engineers, The Institution of Electrical Engineers, The Institution of Mechanical Engineers and Imeko; and supported by the Commission of European Communities.

The conference will provide a forum for the presentation and discussion of recent advances in the sensor field. Topics to be covered include sensor designs, sensor packaging, materials for sensors and multisensor systems and software. The conference theme embraces physical, chemical and biological sensors and their applications. Invited papers include:

Silicon sensors: full of promises and pitfalls
S. Middelhoek (Delft University of Technology)
Sensor materials
W. E. Duckworth (Fulmer Research Institute, Slough)
Solid state chemical sensors
W. Gopel (Tubingen University)
Digital compensation of sensors
J. E. Brignell (University of Southampton)
Biosensors
C. R. Lowe (University of Cambridge)
Optical fibres for sensing
W. A. Gambling (University of Southampton)