1

Armaments in Urology

1.1 Principles of Urological Technology

Shibs Datta

1.2 Wound Healing in the Urinary Tract

Motaz ElMahdy Hassan, Mohamed Ismail

1.3 Simulation in Urology

Hamid Abboudi, Muhammad Shamim Khan, Prokar Dasgupta, Kamran Ahmed

Blandy's Urology, Third Edition. Edited by Omar M. Aboumarzouk.

1.1

Principles of Urological Technology

Shibs Datta

University Hospital of Wales, Cardiff, UK

Abstract

Urology and technology have always been intricately related. Our specialty has been a pioneer of minimally invasive diagnostic and therapeutic approaches which have evolved in complexity and functionality. We started using endoscopes, then innovated with ample use of lasers, and have now introduced the widespread use of robotic assisted surgery. Urologists are challenged to be familiarised with a diversity of devices, which range from flexible, rigid, and semi-rigid endoscopes to a number of lasers with different wavelengths and capabilities.

Keywords *endoscopy; laparoscopy; laser; catheters; stents; guide wires*

Key Points

Optics in Urology

- The introduction of the Harold Hopkins rod-lens telescope into urology has been a significant step in the evolution of endourology.
- Coherent fibre-optic bundle endoscopy enables both high-quality images and light transmission using flexible instruments for the purpose of cystoscopy as well as ureterorenoscopy.

Diathermy and Lasers in Urology

- Diathermy remains widely utilised in urology, exploiting the heat generated when an alternating current passes through a conductor.
- Laser energy is now ubiquitous in surgery and perhaps indispensable for some purposes, such as transmitting energy down a flexible endoscope.

Catheters, Stents, and Guidewires

- Basic knowledge of these commonly used technologies is requited to safeguard appropriate uses of each.

1.1.1 Optics in Urology

Historically, urologists have been defined by their endoscopic skills. This continues to be the case, with advances in optical and camera technology ensuring that urologists remain at the forefront of surgical innovation.

1.1.1.1 The Rod-Lens System

The first cystoscope was introduced by Maximilian Nitze in 1876. Modifications through the first half of the twentieth century changed the device so that it was lit by a heated platinum wire at its distal end [1]. The wire was soon replaced by Edison's electric lamp. The telescope, originally made as an integral part of the instrument, was later constructed so to be removable from a separate sheath through which the instrument could be irrigated. To transmit the image, the telescope had glass lenses and prisms separated by spaces of air (Figure 1.1.1). Limitations of this design include the technical difficulties in engineering small lenses that are of high enough quality to avoid image degradation and peripheral aberration. Metal mounts required for such traditional designs would also reduce light transmission through the telescope.

Late in the 1950s, Professor Harold Hopkins was approached by James Gow, a renowned urologist from Liverpool, with the aim of improving this system. The

Blandy's Urology, Third Edition. Edited by Omar M. Aboumarzouk.

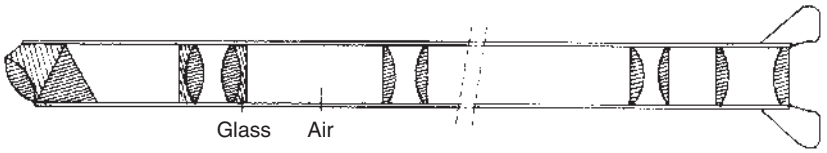

Figure 1.1.1 Diagram of conventional cystoscope. The glass lenses are held in place by metal spacers and separated by air spaces.

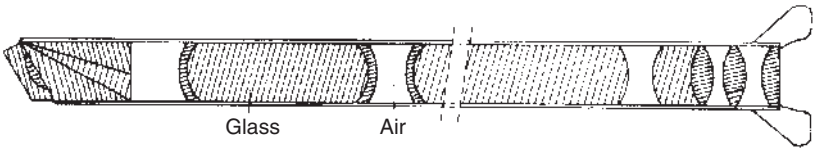

Figure 1.1.2 Rod-lens telescope, with 'lenses' of air, separated by 'spaces' of glass, with no need for metal spacers. *Source:* Courtesy of Professor H. H. Hopkins.

rod-lens telescope reverses the traditional glass-lens system, such that the telescope is, in essence, a rod of glass with air gaps within that act as the lenses (Figure 1.1.2).

Changing the main transmission medium from air to glass doubled the light which could pass through a system of given diameter. A second doubling of light transmission resulted from the omission of the metal spacers, which were no longer needed to position the lenses; the rods could be mounted without them [2].

Furthermore, the refractive surfaces of the rods were technically easier to precisely engineer so that they could be manufactured to a high degree of optical accuracy. Hopkins complemented these improvements by making use of modern glasses, sophisticated computer-aided design, and multilayer lens blooming. The latter minimised internal reflections within the system, improved light transmission, and suppressed stray images [3].

The result of these improvements has been a family of telescopes, each with good optical resolution through an angle of field of 70° or more, with the image quality of a microscope. The angle of view can be varied by incorporating a prism behind the objective lens. The traditional 30° telescope is a throwback to the days of distal illumination and is widely used, not only for cystoscopy, but laparoscopy as well (Figure 1.1.3). Rotating an angulated cystoscope around its axis during endoscopy therefore enables optimal visualisation of a spheroid structure, such as the bladder.

The rod-lens element of the telescope enables image transmission, but illumination is mediated by a separate system incorporated into the telescope design. Parallel to the rod-lens element is a noncoherent fibre-optic bundle (see below). This is not used for image transmission, but it transmits light from an external source (such as a 3000 W xenon-arc lamp) to provide the illumination required.

Problems related to the rod-lens telescope are relatively infrequent, given the precision engineering required in their manufacture and the workload required of them.

Reduced image contrast can occur as a result of a breach of fluid into the telescope system, resulting in

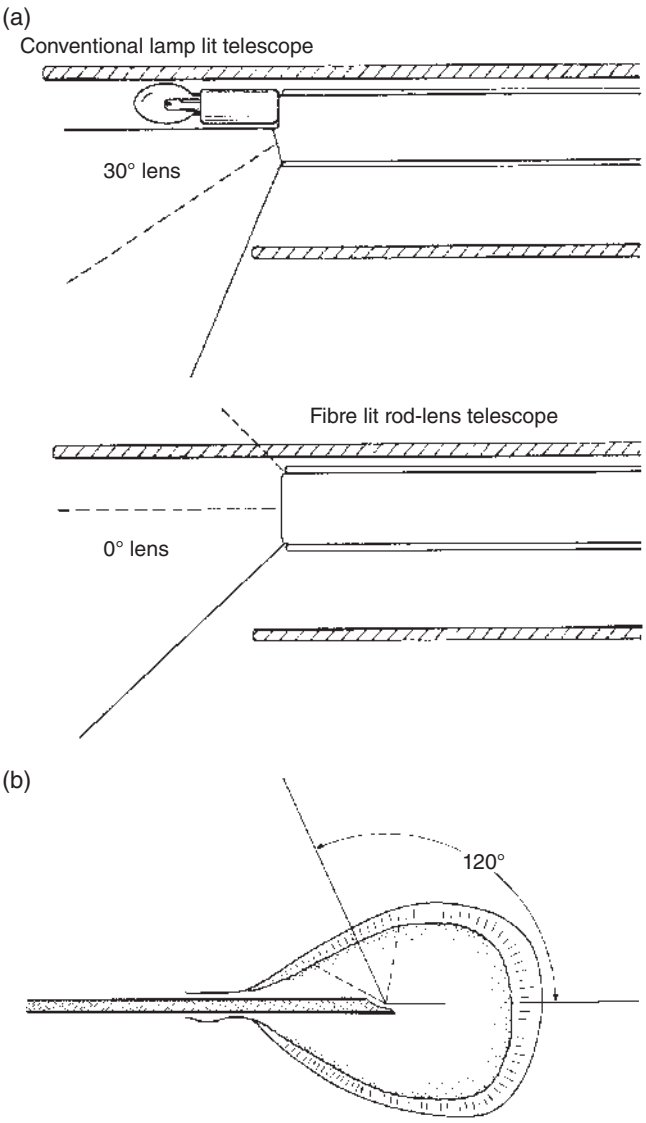

Figure 1.1.3 (a) Comparison between the angle of view offered by the convetional 30° 'fore-oblique' optic and the forward viewing 0° telescope. (b) The tetroviewing 120° telescope allows the bladder neck and anterior bladder wall to be seen clearly.

internal condensation. In these circumstances, the telescope must be immediately sent away for repair or replacement because of the risk of contamination to a patient.

Poor light transmission may be the result of damage to the fibre-optic bundles within the telescope itself that transmit the external light source from the external cable connection to the distal end of the telescope. Sometimes, poor illumination is because of the fibre-optic cable that transmits light from the external light source to the telescope; this can be checked by qualitatively comparing the illumination coming directly from the external cable with the illumination from the telescope itself with light cable attached.

Blurring of the image or loss of some of the image field can be as a result of accretions accumulating on the proximal or distal end of the telescope. Chipping of the rod lens can result in partial blurring when the damage is nearer the eyepiece, but cracking or chipping can sometimes be seen more discretely with more distal telescope damage.

1.1.1.2 Fibre-optic Flexible Endoscopes

Unlike rigid endoscopes which utilise rod-lens technology, flexible endoscopes all use fibre-optic image transmission. The basis of fibre-optics is the passage of light along glass fibres by a process of total internal reflection, hence, why endoscopes can maintain adequate lighting and imagery (Figure 1.1.4). J. L. Baird [4] conceived the idea of using an array of fibres to transmit an image, but it was Hopkins who constructed the first working fibrescope [5].

Each glass fibre consists of a light-transmitting translucent core surrounded by glass cladding with a lower refractive index. Light is transmitted through the fibre via a process called 'total internal reflection', with reflection occurring at the interface between the two transparent materials. As there may be up to 10^4 internal reflections over a 1-m length of fibres, even a small light loss at each one would cause a considerable fall-off in the efficiency of light transmission were it not for the cladding present. The cladding also protects the surface of the fibre core from damage and contamination which would otherwise interfere with internal reflection. Light losses of 50% or less over a 1-m light path can be achieved.

The glass fibre core and cladding is arranged in bundles that may be coherent or non-coherent. Coherent bundles are arranged such that the proximal position of each fibre with respect to the entry face maps precisely to the corresponding position of the fibre distally on the exit face of the flexible instrument. This enables light focusing on the distal face of the endoscope to be transmitted precisely to create an identical image at the proximal face of the endoscope.

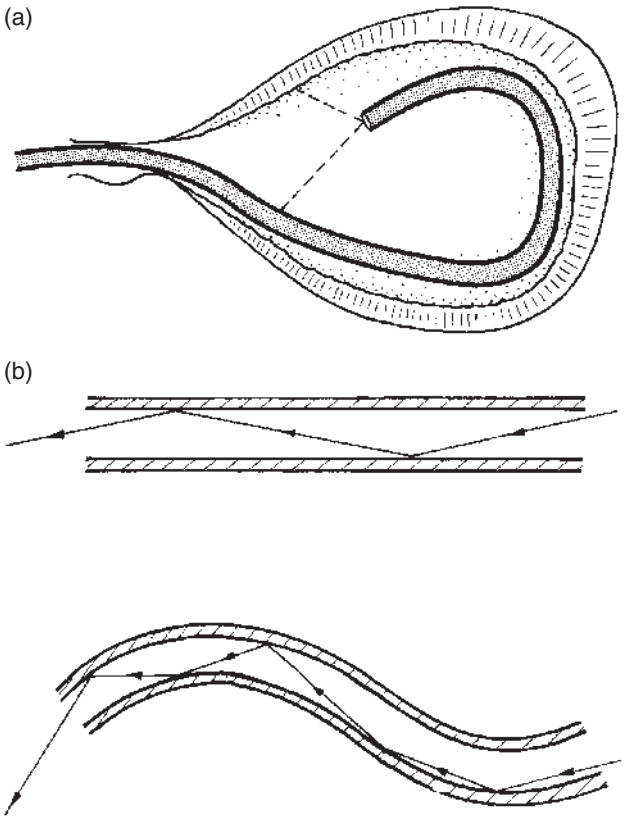

Figure 1.1.4 (a) A flexible cystoscope looking back at itself the 'J manoeuvre'. (b) Total internal reflection permits light to travel along a flexible glass fibre.

Noncoherent fibre bundles are such that the fibres are arranged randomly, enabling light but not image transmission. In urology, flexible cystoscopes, semi-rigid ureteroscopes, and flexible ureteroscopes all utilise coherent fibre-optic technology, whereas light-transmission cables are incoherent fibre bundles. The individual fibres within endoscopes are typically smaller than for light-transmission cables, but the principles underlying both coherent and noncoherent fibre bundles are essentially identical.

1.1.2 Surgical Energy

1.1.2.1 Diathermy

Surgical diathermy utilises the principle that as a current passes through a resistor, heat is dissipated. This results in a temperature rise, and from a surgical perspective, controlled tissue cutting and coagulation [6].

An alternating current from the domestic mains causes such tissue heating, but at 50 Hz, it can also cause electrocution and ventricular arrhythmias, resulting in a potentially fatal outcome.

The underlying principle of safe diathermy (amongst other factors) is not a function necessarily of high or low voltage or current, but of the kHz range frequency at which neurophysiological conduction and axon depolarisation seem to be refractory. A low-frequency current as small as 1 mA can induce fatal cardiac arrhythmias, but at radiofrequencies (500–5000 kHz), neurophysiological conduction does not occur, and currents as high as 2 A can therefore be used for surgical diathermy.

Surgical diathermy exploits the heat generated when an alternating current passes through a conductor. When there is a large density of electrical current passing through tissue, the temperature rise can be enough to give a useful surgical effect. In monopolar diathermy, the surgeon uses a small active electrode to give a high current density and a large heating effect at the operative site at a frequency of about 200 kHz. Because the current density near the large return electrode, which completes the circuit, is small, it produces little heat. In bipolar diathermy the thermal effect occurs in tissue held between two small active electrodes and does not pass through the patient's body which is not being treated. Bipolar frequency is between 250 kHz and 1 MHz.

Nerves and muscles are stimulated by alternating current of low frequency (faradism), but this faradic effect does not occur when the frequency exceeds a certain value as neurophysiological conduction becomes refractory as such frequencies. Surgical diathermy is used for both cutting and coagulation. A pure cutting current utilises an alternating current which is constant; the root mean square of such a waveform enables energy to be delivered at a sufficient level to vaporise intracellular water with cell destruction, achieving very high current densities. For electro-coagulation, the diathermy waveform consists of bursts of alternating current between periods of rest (all still occurring at high frequency), resulting in protein denaturation (and hence thermocoagulation), without vaporisation. The dead tissue is shrunken and desiccated in situ – distortion of the walls of blood vessels, coagulation of plasma proteins, and stimulation of the clotting mechanism all act to check bleeding. Ideally, intracellular temperatures do not reach 100 °C so there should be no unwanted cutting.

1.1.2.2 Contact Diathermy

In contact diathermy, the main impedance (resistance) to current flow is at the interface between the electrode and tissue, where it is influenced by the type of tissue and its state of hydration. The impedance of fat is high compared to muscle, and contact diathermy works less efficiently on adipose tissue. As diathermy proceeds, the tissue in contact with the electrode dessicates and electrical impedance rises. Eventually, the current flow is insufficient to produce further heating and the surgical effect ceases. This limits the depth of penetration of diathermy applied to one spot. The effect of contact diathermy also depends on the size and shape of the active electrode. A ball electrode with a large surface area held in contact with tissue will tend to apply current at a relatively low density, giving a coagulating effect, but the depth of tissue coagulated is proportional to the square of the diameter of the ball. Contact cutting by point diathermy is mainly by physical disruption of tissue softened by coagulation and is usually less effective than noncontact cutting.

1.1.2.3 Noncontact Cutting

Contact with tissue is necessary in bipolar diathermy but most urological diathermy is monopolar and noncontact. For current to cross a gap between a resectoscope loop and the prostate it must be driven by a sufficient voltage to ionise the intervening medium and produce a spark. (A spark is a less sustained discharge than an 'arc'.) Once established, a spark produces the very high temperatures needed for cutting. However, most of its energy is dissipated near the tissue surface, and little is available to give the gentler heating needed for deeper coagulation and haemostasis.

The cutting current is a continuous simple sine wave. The peak voltage provided is enough to give short, intense sparks which produce enough local heat to explode cells into steam (Figure 1.1.5). There is little coagulation and the cut is 'pure'. For coagulation, the electrical energy must be applied more slowly so that the heat to which it is converted has time to spread below the surface of the tissue (i.e. the power supplied must be reduced).

In contact diathermy, so long as the effective voltage is sufficient to overcome the impedance of the contact interface, coagulation can be obtained by reducing the voltage of the sine wave current. Alternatively, the current density can be reduced by increasing the contact surface of the electrode.

A high voltage is essential to drive the spark in noncontact diathermy, and a different method must be used for coagulation. The total current supplied in a given time, hence the rate of heating, is reduced by applying the current in bursts. In the gap between the bursts, no current flows. Because the coagulation current is turned off most of the time, it can have large peak voltages and currents but actually deliver much less power than a continuous cutting current. Fulguration (literally flashing like lightning) is provided by a current with an interrupted waveform. This has a high peak voltage but the effective power can be the same as a cutting current with a much lower voltage peak. The resulting sparks are longer, and there is more sustained tissue heating leading to coagulation and haemostasis. The high peak voltage

(a)

Comparison of diathermy settings

Cutting	Coagulation
Continuos output, 100% on	Pulsed output, 6% on
Low voltage	High voltage
Non-contact mode: vaporisation and cutting	Non-contact mode: fulguration
Contact mode: desiccation	contact mode: desiccation
Intense heat, 1000°C	Less heat
Charring/spread low	Charring/spread high
Power 125–250 W	Power 10–75 W
Sufficiently high power density is applied to vaporise the water content of tissues, i.e. vaporises and explodes a small section of soft tissue.	Tissue remains grossly intact, but cells are destroyed at the point of contact, and smaller vessels are destroyed and sealed.

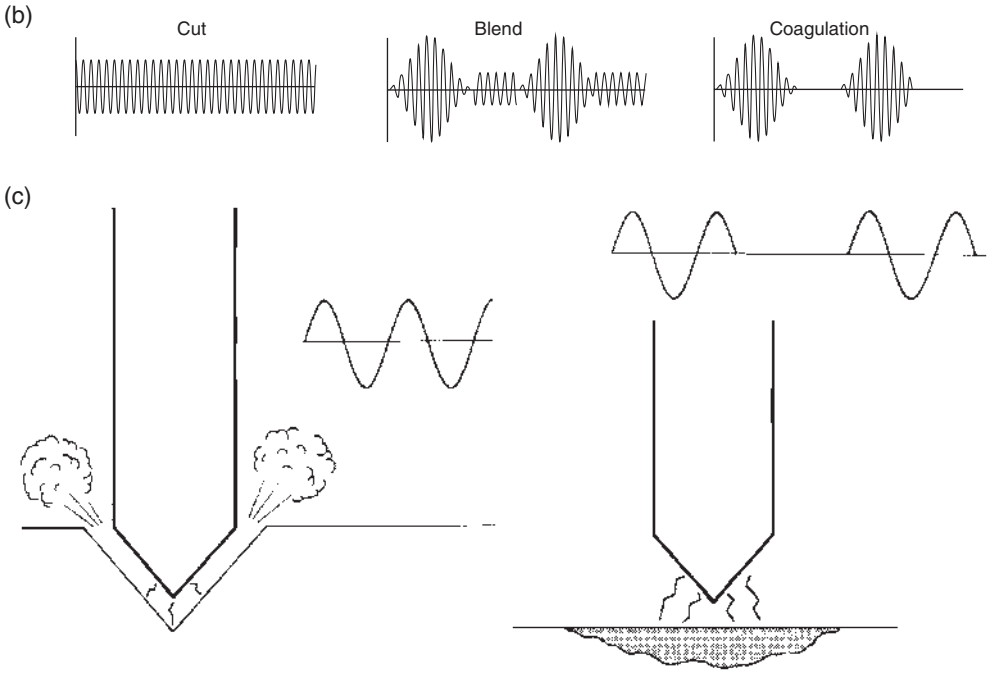

Figure 1.1.5 (a) Typical diathermy waveforms. (b) Cutting current: a continuous sine wave provides short intense sparks, which explode cells into steam, but there is little heating below the surface and little coagulation (i.e. continuous high current, low voltage) (c) Coagulating current: short bursts of sine waves provide localised heating leading to coagulation (intermittent low current, high voltage).

can drive current through the high impedance of desiccated tissue: thus fulguration can continue until carbonisation or charring occur.

In summary, the 'cut' current is typically a continuous sine wave, producing sparks whose heat explodes intracellular water to steam. The 'coag' current is a sine wave current supplied in bursts, which allows the sustained heating in depth needed for coagulation (Figures 1.1.5b and c). Peak voltage and mean power output can be varied by adjusting the duration of bursts of current to give a combination of cutting and coagulation; this is known as 'blended' current.

Diathermy output settings, that can be varied, are normally measured in Watts (Joules per second) and are the product of the voltage and current.

1.1.3 Dangers

1.1.3.1 Electrocution

Diathermy machines are manufactured to national and international safety standards which minimise the risk of any part of the machine becoming live with mains current. As with any electrical device, servicing must be regular and expert.

1.1.3.2 Fire and Explosion

Ignition of alcohol-based solutions used for skin preparation is a well-recognised complication of diathermy which is still reported each year by the medical defence

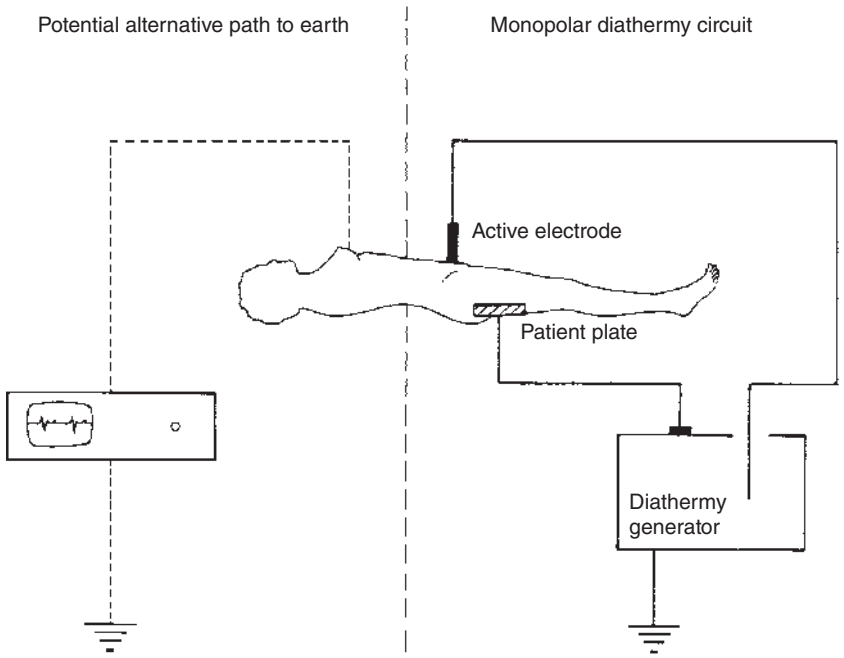

Figure 1.1.6 Monopolar diathermy generators are ground referenced by earthing the patient plate to the metal case of the device. There is a risk of a burn if the patient plate is incorrectly attached, and there is contact with any other earthed point (e.g. patient monitoring equipment).

societies. It occurs when the flammable fluid is allowed to pool on or under the patient. The surgeon must take care that all excess spirit is removed before using diathermy. Better still, disinfecting fluids containing alcohol should be avoided if a suitable aqueous alternative is available. Thankfully, explosive gases are rarely used in modern anaesthesia. If they are, diathermy is an unnecessary hazard and should be avoided.

1.1.3.3 Burns

Burns are the most common type of diathermy accident. They occur when the diathermy circuit is completed in some way other than that intended by the surgeon, usually an unauthorised flow of current to earth. Most monopolar generators are ground referenced by earthing the patient plate side of the output transformer via the metal case of the device (Figure 1.1.6). If the active electrode is touched to any earthed object, current will flow. When the system works properly, heating occurs only at the tip of the active electrode. The current passes through the patient's body and escapes safely via the return electrode. Unfortunately, this long current path offers opportunities for alternative unwanted passage of current to earth. If the patient electrode is incorrectly attached, there is a danger that the circuit might be completed by a small earthed contact point. If the current density at this point is sufficient, the patient will be burned.

Most devices monitor the attachment of the patient plate and sound an alarm when contact is inadequate. A simple method is to attach the plate by two wires through which a small current flows: if a wire breaks, the current is interrupted and the diathermy can be automatically inactivated. This checks the integrity of the connection of the plate to the diathermy machine. It does not guarantee that the plate itself is properly attached to the patient. Another safety device uses a small direct current, which by passing through the active electrode, the patient, and the patient electrode, monitors the integrity of the whole diathermy circuit. Other machines have even more sophisticated safety measures; however, it remains the surgeon's duty to ensure that an appropriate plate is used and to supervise its attachment to the patient.

Unfortunately, burns may still occur at small earthed contact points where current will flow at the expense of even a correctly attached return plate. All patient monitoring equipment should be isolated from the earth wherever this is possible. Electrocardiograph electrodes should be well gelled and of large enough area to disperse the current. Needle electrodes should never be used. As a general rule, the return pad should be sited as near to the operation area as possible so that the main current path will be distant from other potential routes that the current might take to ground.

Pressure on the footswitch of most machines leads to activation of all the active electrodes which are connected. Any devices which are not in use must not be in contact with the patient. An unused electrode should be safely stored in an insulated quiver where it will be safe if the footswitch is inadvertently activated.

The surgeon and assistants are also liable to suffer burns when using diathermy equipment because they constitute an effective alternative path to earth. Such burns are particularly likely in the practice of 'touching'

the live electrode onto another metal instrument such as tissue forceps grasping a bleeding vessel. Surgical gloves are not effective insulation against diathermy current, especially if they are holed. The person holding the instrument, often an unfortunate assistant, may receive a small but deep and painful burn.

Bipolar diathermy is intrinsically safer than monopolar diathermy because current passes between two small electrodes on the same handpiece. Secondary currents induced by the main radiofrequency may leak to ground, but they are too small to cause trouble. Unfortunately, in most urological applications, bipolar diathermy is not as useful as monopolar diathermy.

1.1.3.4 Neuromuscular Stimulation: The 'Obturator Twitch'

Although the high-frequency current used for surgical diathermy does not cause neuromuscular stimulation, the sparks which it induces may invoke secondary currents which can do so. The sparks make random electrical 'noise' in the midst of which are alternating frequencies able to induce a faradic effect. Such currents can be electronically suppressed by capacitors in the circuit. However, they may be sufficient to cause trouble in the special conditions of diathermy in the region of the ureteric orifices close to the course of the obturator nerve and the psoas muscle. The problem is seen with both 'cut' and 'coag' currents and can usually be abolished by full chemical neuromuscular blockade.

1.1.3.5 Pacemakers and Diathermy

Implanted pacemakers are not uncommon in patients who are elderly and come to urological surgery. Diathermy currents can interfere with the working of pacemakers, causing possible danger to the patient. This was more of a problem with some of the previous fixed-rate devices, which could be fooled into delivering stimulation at such a high rate that dangerous dysrhythmias could result. Modern pacemakers are designed instead to be inhibited by high-frequency interference so that the patient may receive no pacing stimulation at all while the diathermy is in use. Some demand pacemakers revert to a fixed rate of pacing, and it is essential to have a magnet available so that they can be reset if necessary.

A number of additional precautions are wise in these patients. First, if monopolar diathermy is to be used, the patient plate should be sited so that the current path does not pass through the heart or the pacemaker. Second, the heartbeat should be monitored throughout the operation. Lastly, a defibrillator should be on hand in case a dangerous dysrhythmia develops through malfunction of the pacemaker.

Precautions to avoid complications:

- Diathermy pad: over well-vascularised area, away from any prosthesis, underlying skin free from scarring or hair, 70–150 cm^2
- Avoid inflammatory liquids, such as alcohol-containing skin prep
- Patient should avoid contact with any other metal (e.g. drip stand)
- Avoid touching any other instruments with diathermy
- Pacemaker/ICD
  - Is surgery necessary?
  - Check with cardiologist or pacemaker clinic. May need preoperative check or reprogramming (fixed rate/monitor only sometimes via clinical magnet) and postoperative check.
  - Ask patients to bring their card with all details.
  - Diathermy pad away from pacemaker and electrocardiogram leads, diathermy machine away from pacemaker, use bipolar diathermy if possible, continuous heart rate monitoring, defibrillator and external pacemaker to be available, short bursts of diathermy, minimise operative time.
  - Prophylactic antibiotics: avoid fluid overload.
  - Postoperative check if surgery was an emergency.

1.1.4 Urological Diathermy

Transurethral resection requires high-power monopolar diathermy currents which must be handled with great care. Typically, higher power output settings are required (e.g. 160-W cutting/60-W coagulation compared to 30–40 W for open surgery) because the use of irrigation fluid rapidly dissipates the intense heat required. There is an almost inevitable leakage of diathermy current from the loop to the metal instrument which poses a potential danger to both the surgeon and the patient. Most resectoscopes now have an all-metal design with an insulated beak so that current that travels into the instrument is free to leak from it into the urethra. This is not usually a problem because the area of contact with the urethra is sufficient to make a burn unlikely. However, if through some fault, the loop comes into direct contact with the sheath, the full diathermy output will be applied to the urethra.

A fully insulated sheath might be expected to give protection against this hazard; unfortunately, this has dangers of its own. Damage to the insulating layer will lead to unpredictable leakage into the patient or the surgeon. If the loop should break and make contact with the metal frame of the instrument, a large current could flow to ground via the surgeon's body. Such currents are usually prevented by the return fault circuit of the machine, but small and significant currents may pass to ground during fulguration.

Conducting lubricating gels should be used with all metal resectoscopes to avoid the possibility of preferential conduction at sites where the gel is thin or absent. By contrast, petroleum jelly or mineral oil, which do not conduct electricity, must be used only with an insulated sheath because these lubricants cannot provide an alternative path between the loop and the urethra, and they always end up smearing the lens.

1.1.4.1 LigaSure Diathermy

This utilises pressure and energy to seal vessels. It is a bipolar device which allows the administration of high current and low voltage energy (180 V) and high coaptive pressure during the generation of tissue temperature under 1000 °C, which results in sealing of vessels up to 7 mm in diameter. Once the energy is applied, the hydrogen cross-links rupture and then renature, resulting in a vascular seal that has high tensile strength. The melted collagen and elastin in the vessels form a permanent seal.

1.1.4.2 Harmonic Scalpel

The harmonic scalpel utilises ultrasound energy to cause coagulation at lower temperatures than electrosurgical equipment (50–100 °C compared with 150–400 °C). Coagulation occurs by the coaptation or compression of the vessels walls followed by denaturing protein when the instruments blades vibrate at 55 500 Hz (i.e. 55 500 vibrations/s). The ultrasound transducer located in the hand piece is composed of piezoelectric crystal sandwiched under pressure amongst metal cylinders. The ultrasound generator converts ultrasonic energy into mechanical energy or the vibrations.

This comprises the utilisation of both the harmonic scalpel and the LigaSure, by simultaneously delivering ultrasonically generated frictional heat energy and electrically generated bipolar energy.

1.1.5 Lasers in Urology

LASER is an acronym for light amplification by the stimulated emission of radiation. Laser energy is now ubiquitous in surgery and perhaps indispensable for some purposes, such as transmitting energy down a flexible endoscope (e.g. holmium: YAG laser ablation of upper tract stones via a flexible ureterorenoscope).

Laser energy is light energy which, like electromagnetic radiation in general, may interact with matter to create heat and other phenomena. The characteristics of light is that it is that form of electromagnetic radiation defined by its ability to be perceived by the human eye, although infrared and ultraviolet radiations, which also interact with biological systems, are included within this definition. The wavelengths of visible light range from 400 nm (violet) to 760 nm (red) and form only a small part of the electromagnetic spectrum [7].

Laser light differs from conventional white light only in that it is:

1) Monochromatic: consisting of light waves propagating at a single frequency
2) Collimated: the photons propagate in parallel via narrow beams with little divergence, resulting in high pinpoint irradiance.
3) Coherent: the propagated waves are such that wave peaks and troughs are in phase.

Electromagnetic radiation propagates in wave form, characterised by a frequency (ν), which is inversely proportional to its wavelength (λ) and related to the speed of light as follows:

$$C = \lambda \nu$$

where c is the velocity of light in a vacuum (2.99×10^8 $m\,s^{-1}$). 'White light', such as sunlight, is polychromatic with a wide distribution of wavelengths.

All types of electromagnetic radiation have mutually perpendicular coupled electric and magnetic fields which are able to interact with the electrons and nuclei of the atoms that comprise matter. The predominant interaction is that of the electric field component with the negative charge of electrons. Towards the end of the nineteenth century, it was realised that many aspects of electromagnetic radiation could be more accurately understood by regarding the radiation as comprising discrete particles or packets of energy called 'quanta' or photons. A key principle of quantum physics is dual wave/particle nature of matter. This is key to understanding how laser light (along with all electromagnetic radiation) has both particulate properties (in the form of photons) and waveform characteristics.

1.1.5.1 Basis of Energy Generation in LASERs

Lasers require:

1) An energy source. This is sometimes called a 'pump source' and may consist of an electrical flashlamp, arclamp, electrical discharge, chemical reaction, or another laser. A helium-neon (HeNE) laser typically utilises an electrical discharge, whilst a Nd:YAG laser utilises a Xenon flash lamp.
2) A gain material, or laser material. This is the medium which determines the wavelength of the laser output and the source of photons from exciting electrons in that medium. Examples of lasers in urology include KTP:YAG and Ho:YAG devices.

3) An optical resonator. A simple example would be a paired parallel mirror on either side of the gain material, one mirror being partly reflective. This enables the photons to oscillate between the mirrors within the gain material, resulting in amplification prior to light emission.

The pump source excites electrons to a higher orbital or energy level. The laws of quantum physics 'allow' electrons to occupy only certain discrete energy levels. When the excited electrons relax, or decay, to their ground state, they emit a photon, the energy of which is discrete and precise for the particular laser material and corresponds to the transition energy between the excited and ground state (Figure 1.1.7). This emission of a photon from the transmission from excited to ground state is called 'stimulated emission'. The emitted photon has a precise wavelength defined by this change in the discrete energy levels, and hence the monochromatic nature of laser light. The basic construct of a laser is illustrated in Figure 1.1.8.

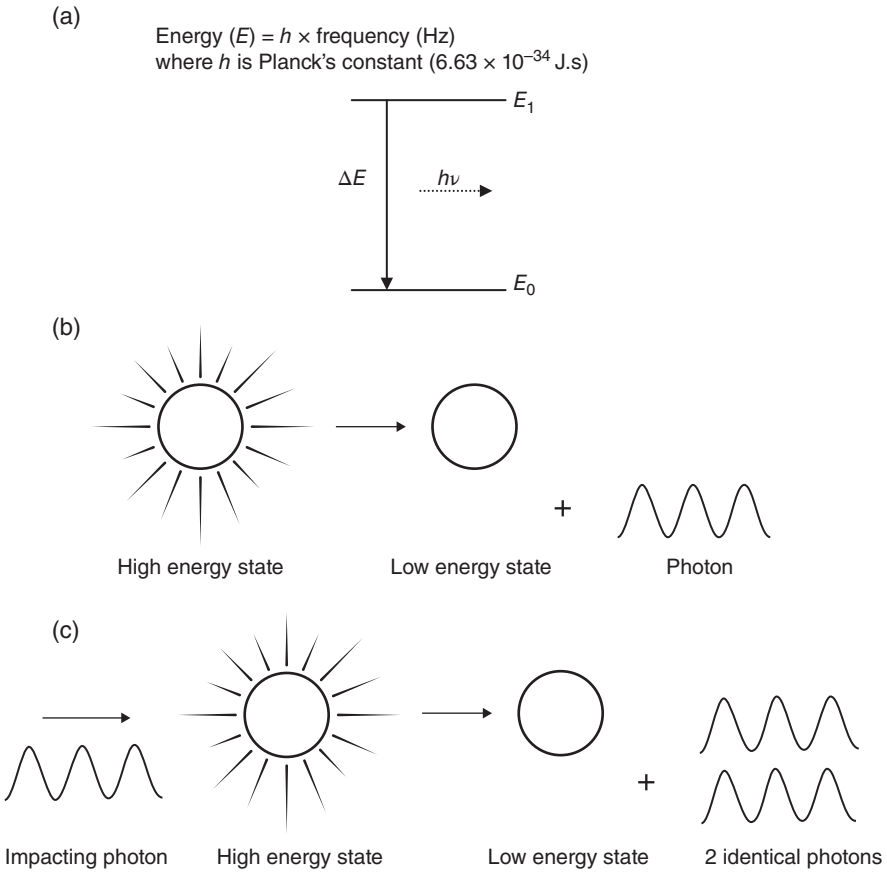

Figure 1.1.7 (a) Photon emission with electron transition. (b) Photons are emitted when a particle changes from a higher to a lower energy state. (c) The impacting and emitted photon have the same wavelength and are discharged in phase; two photons emerge where only one went in.

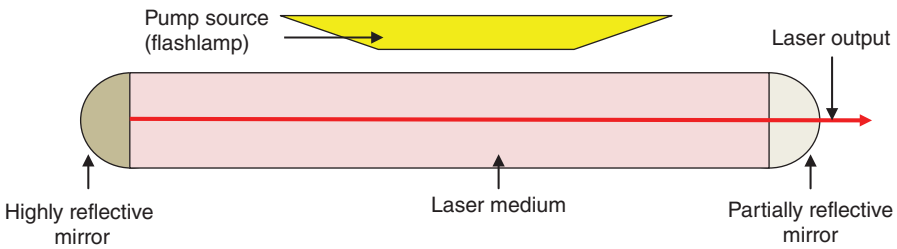

Figure 1.1.8 Laser construction. The active laser medium is contained between mirrors. Energy is pumped into the laser medium from a power source to propel more particles into a higher energy state. In stimulated emission, phonts radiate in all directions. Only those which are parallel to the axis of the laser cavity emerge through the front mirror as the laser beam.

1.1.5.2 Laser Interface with Tissue

When photons from a laser interact with the surgical field, there are several potential outcomes for the incoming beam:

1) *Reflection* – a small percentage of the incoming laser light is reflected at the interface between the transmitting medium and the operative surface. This may cause some collateral heating but is not usually of clinical significance.
2) *Scattering* – this is a function of both the tissue operated on and the wavelength of laser used. Longer wavelength laser light (i.e. lower frequency) towards the red/infrared end of the spectrum tends to scatter less than shorter wavelength blue/violet light.
3) *Extinction length* – this is the attenuation of the laser light in tissue and is an important function of laser wavelength and an important consideration because it informs as to the depth of necrosis or tissues heating for a given laser. In general, lasers operating at shorter wavelengths (e.g. green light lasers) will have greater depth of penetration than infra-red Holmium:YAG lasers, which have an extinction length of less than 0.5 mm.
4) *Absorption* – this is the most important phenomenon for surgery, by which the laser light interacts with tissue or stone to create the cutting, vaporisation, or coagulation effect required by the urologist. Absorption of photons can only occur when there is a chromophore presence (i.e. a set of chemical bonds or molecules which interact with incoming photons to obliterate that photon, excite the chromophore, and enable the conversion of light into heat energy). Fortunately, human tissue consists largely of chromophores, including water and blood. Different tissues absorb different wavelengths of laser light with varying optimisation (i.e. the absorption spectra will be molecule- and tissue-specific). For example, green light (KTP:Nd:YAG operating at 512 nm) operates at one of the absorption peaks of haemoglobin. Blood is red when illuminated by conventional white light because haemoglobin molecules absorb green and blue light, reflecting predominantly red light back into our retinas. Conversely, Holmium:YAG laser light operates at the invisible infrared part of the spectrum, which is optimally absorbed by water.

1.1.5.3 Clinical Applications

Lasers in urology are used predominantly for the surgical treatment of benign prostatic enlargement (BPE) and urinary tract stone disease. Laser light can be transmitted via fibreoptic technology, enabling the transmission of energy through flexible endoscopes. Lasers that emit light efficiently absorbed by water or haemoglobin enable it to effectively cut, coagulate, and vaporise in the treatment of BPE. Table 1.1.1 summarises the lasers that are currently used in urology.

1.1.5.3.1 Lasers in the Management of Urinary Tract Stones

The Ho:YAG produces light at a wavelength of 2100 nm in a pulsed fashion. At this far infrared frequency, water is absorbed to produce localised heating and tissue or stone destruction. The energy can be varied from 0.2 to 2.8 J/pulse and the frequency from 5 to 30 Hz, giving powers of up to 100 W. The light can be transmitted along low-water-density fibres and, unlike the CO_2 laser, can be carried through a flexible fibre. This makes the Ho:YAG laser ideal for stone treatment using flexible-ureteroscopy, and therefore enables minimally invasive retrograde treatment of even the most inaccessible of upper tract stones. Other ureteroscopic modalities for treating stones either require a rigid instrument (e.g. lithoclast) or are unacceptably dangerous in the modern era of clinical governance (electro-hydraulic lithotripsy). Typical power settings for laser lithotripsy are arbitrary but are often set with the pulse frequency in Hertz (Hz) numerically 10 times the energy setting in Joules (J). Examples of settings used for laser lithotripsy via the flexible ureteroscope are from 0.6 J at 6 Hz to 1.5 J at 15 Hz. The product of these settings gives the power output in Watts ($\equiv \mathrm{J\,s^{-1}}$):

$$\mathrm{Power(W)} = \mathrm{Energy(J)} \times \mathrm{Frequency(Hz)}$$

Laser transmission via a 200-μ fibre and flexible ureteroscope can enable stones to be potentially treated anywhere in the urinary tract. Scenarios which have now made the Ho:YAG laser an essential part of the urological armamentarium are summarised as follows:

- Minimally invasive treatment, in a single sitting, of an upper ureteric stone beyond the reach of a rigid ureteroscope.
- The scenario where lithoclast treatment of a lower or middle ureteric stone via the rigid ureteroscope transmits the stone upward, beyond the reach of conventional instrumentation. In these circumstance, one could then 'chase' the stone using a flexible ureteroscope and Ho:YAG laser.
- Treatment of a lower calyceal stone, resistant to extracorporeal lithotripsy (ESWL), may be carried out by manipulating the flexible ureteroscope retrogradely into the calyx and allowing disintegration using the Ho:YAG.
- Similarly, stones in calyceal diverticula can be treated by retrogradely incising the diverticulum using the flexible ureteroscope and and then treating the stone with the Ho:YAG laser.

Table 1.1.1 Lasers used in urology.

Laser Medium	Abbreviation/ Acronym	Wavelength (nm)	Procedure	Absorption
Holmium: Yttrium-Aluminium-Garnet	Ho:YAG	2140	Holmium Laser lithotripsy Holmium laser resection of prostate (HoLRP) Holmium laser enucleation of prostate (HoLEP)	Water
Neodymium: Yttrium-Aluminium-Garnet	Nd:YAG	1064	Visual laser ablation of prostate (VLAP) Interstitial laser coagulation of prostate (ILP)	Water and haemoglobin
Kalium titanyl phosphate: Yttrium-Aluminium-Garnet	KTP:Nd:YAG	532	Photoselective vaporisation of the prostate (PVP) GreenLight™ vaporisation GreenLight XPS™ vaporisation	Haemoglobin
Lithium Borate: Yttrium-Aluminium-Garnet	LBO:Nd:YAG	532	Photoselective vaporisation of the prostate (PVP)	Haemoglobin
Thulium: Yttrium-Aluminium-Garnet	Tm:YAG	2013	Thulium laser vapoenucleation of prostate (ThuVEP) Thulium laser vaporisation of prostate (ThuVAP) Thulium laser vaporesection of prostate (ThuVARP) Thulium laser enucleation of prostate (ThuLEP)	Water
Diode Lasers		830	Interstitial laser coagulation of prostate (ILP)	Water and haemoglobin
		940, 980, 1318, 1470	Vaporisation	
Dye Laser		405	5-Aminolevulinic Acid (ALA) mediated Photodynamic Therapy (PDT)	Haemoglobin

- Treatment of calcium oxalate monohydrate and cystine stones. These stones are hard and may be resistant to ESWL or the lithoclast. The Ho:YAG laser is capable of destroying these stones.

1.1.5.3.2 Lasers in BPE

Despite the numerous laser procedures for BPE that have emerged and, together with their acronyms, have become obsolete over the years, the principle of laser surgery for BPE is relatively straightforward. Photons, which have both particle and wavelike properties, have intrinsic energy inversely proportional to their wavelength and can be absorbed by, for example, haemoglobin or water to create heat which results in coagulation and protein denaturation or vaporisation. All the techniques briefly described here are generally easy to learn (except for the HoLEP), have excellent haemostatic properties, utilise saline as the irrigating fluid of choice, and enable surgery to be carried out as day case or < 24-hour-stay surgery.

Lasers for treating BPE were first used in the early 1990s with the visual laser ablation of the prostate (VLAP), utilising a 1064 nm Nd:YAG laser. This relatively long wavelength delivers a relatively low-energy density, resulting in protein denaturation and a subsequent coagulative necrosis, with a delayed bulking effect. The subsequent sloughing of prostatic tissue resulted in persistent irritative symptoms lasting months.

Interstitial laser coagulation (ILC) involved heating tissue by directly placing a Nd:YAG fibre directly into prostatic tissue under endoscopic guidance, and although blood loss was minimal, prolonged catheterisation, chronic dysuria, and a high reoperation rate were significant drawbacks [8].

The GreenLight™ Laser vaporises tissue by delivering much higher energy densities. This laser utilises a ND:YAG laser, which is frequency-doubled (wavelength-halved) to 532 nm, using potassium-titanyl-phosphate (KTP) crystals. This wavelength is strongly absorbed by haemoglobin and has a low extinction length, resulting in vaporisation with a low surrounding radius of coagulation. A newer generation GreenLight XPS™ MoXy™ Laser utilises a high maximum power output of 180 W, with a good safety record in patients who are anticoagulated, but long-term results pending [9].

The Holmium: Yttrium-Aluminium-Garnet (Ho:YAG) laser produces a pulsed wavelength of 2140 nm. This is strongly absorbed by water, enabling precise prostatic tissue vaporisation and hence cutting, with minimal charring and a very short extinction depth. The technique of Ho:YAG enucleation (HoLEP) is different from other laser techniques in that the prostatic adenoma is enucleated in the plane between the adenoma and false surgical capsule, with the lobes subsequently removed with a tissue morcellator. It seems that this technique, whilst taking longer to learn and may also utilise more theatre time than a standard transurethral resection of the prostate (TURP), seems to have long-term results at least as good as TURP [10].

1.1.6 Catheters

Urinary catheters are the most used technology in urology for not only therapeutic means, but also diagnostics. It has been in use since 3000 BCE. The word 'catheter' is derived from the Greek 'to let down' or 'send down.'

Catheters are classified base on a number of factors collectively:

- Size: the outer diameters measure by 'French' or 'Charriere' gauge, which refers to the outer circumference in millimetres. Newborn catheters: 4–6 Fr; Infants: 6–8 Fr; Children: 10–12 Fr; Adolescents and adults: 10–34 Fr. The Fr is 3 times the diameter in millimetres (i.e. a 1 Fr has an external diameter of 1/3 mm, therefore the diameter of a catheter in millimeres can be calculated by dividing the Fr by 3) [11].
- Channels: 1-, 2-, or 3-way catheters; (one-way catheters are the in and out intermittent self-catheterising catheters)
- Balloon size: 3–30 ml
- Tip design: Foley and Coude are the more commonly used types (Figure 1.1.9)
- Materials: Polytetraflouroethylene (PTFE)-coated, latex-coated, complete silicone, or polyvinyl chloride.
- Length of required use: short term (e.g. PTFE coated which can be left for 28 days), long term (e.g. latex-coated and silicone catheters which can be left for three months).
- Others types of catheters such as polyvinylpyrrolidone (PVP) and salt coated create a self-lubricating aqueous layer good for intermittent catheterizations.
- Colour coded (Table 1.1.2).

1.1.6.1 Indications

- Relief of obstruction
- Irrigation of bladder
- Drainage to allow healing (low bladder pressure)
- Prevention of reflux with stented ureter
- Empty bladder prior to abdominal or pelvic surgery
- Monitoring of urine output
- Delivery of bladder instillations
- Identification of bladder neck perioperatively
- Incontinence
- Urodynamics

1.1.6.2 Complications of Catheters

1) Localised trauma: Creation of false passages if prostate is enlarged causing difficulty to insert the catheter. This can cause a self-limiting bleed, but

Table 1.1.2 Colour coding for different catheter sizes.

10 Fr	Black
12 Fr	White
14 Fr	Green
16 Fr	Orange
18 Fr	Red
20 Fr	Yellow
22 Fr	Violet
24 Fr	Blue

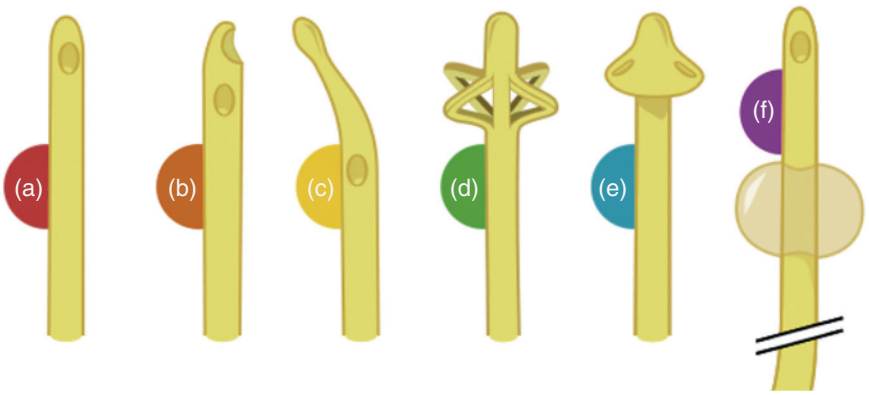

Figure 1.1.9 (a) Side open, (b) Whistle tip, (c) Coude tip, (d) Mallecot, (e) Mushroom tip, (f) Foley.

occasionally the bleeding might need cystodiathermy to control. Strictures (50% of strictures are instrumentally caused) and traumatic hypospadias.

2) Urinary tract infections (UTIs): Asymptomatic bacteriuria invariable occurs in all catheterized patients and is time associated at a rate of about 3–10 % $^{-1}$day^{-1} and reaching 50% by day 10, and nearly 100% by day 28. Nearly 80% of hospital-acquired UTIs are catheter related. The mechanism behind catheter-related infections is the biofilm produced by bacteria. A biofilm is an aggregate of microorganisms in which cells adhere to each other on a surface such as a stent or catheter. These cells are embedded within a self-produced matrix of extracellular polymeric substance (EPS). This substance or slime is composed of material such as proteins, polysaccharides, and DNA. Produced by many types of bacteria, more commonly *Staphylococcus aureus* and *Proteus* spp. Protozoa and fungal infections can also produce biofilms.

Biofilm formation (Figure 1.1.10):

1) Initial attachment through weak, reversible adhesion via van der Waals forces.
2) Irreversible attachment anchors themselves more permanently using cell adhesion structures such as pili.
3) Maturation I and II provides more diverse adhesion sites; build the matrix. Once colonisation has begun, the biofilm grows through a combination of cell division and recruitment
4) Dispersion enables biofilms to spread and colonise new surfaces including tissue such as the bladder, ureter, or renal calyces' walls. Enzymes that degrade the biofilm extracellular matrix, such as dispersin B and deoxyribonuclease, may play a role.

The EPS matrix protects the cells within it and facilitates communication amongst them through biochemical signals. Some biofilms contain water channels that help distribute nutrients and signalling molecules. This environment results in increased resistance to antibiotics because the dense extracellular matrix and the outer layer of cells protect the interior of the community. One factor in bacterial persistence is the ability of bacteria to grow within biofilms.

1.1.6.2.1 Treatment

Management of recurrent UTIs is difficult in these patients, but essentially regular bladder washouts, reduced frequency of catheter change, and increased fluid intake are the key points. Regular or prophylactic antibiotics work invariably and should be given if the patients are symptomatic.

1) Encrustation and stones (25% at five years) and repeated blockages and bypassing: this is based on similar principles of infected stone formation. The urine needs to be alkalinize to pH > 7.2, presence of urease-producing bacteria which hydrolyses urea to ammonia and carbon dioxide (Figure 1.1.11). The high-urinary pH with ammonia leads to crystallisation of magnesium, calcium, and ammonium phosphate (i.e. triple phosphate). Urease-producing bacteria: *Staphylococcus*, *Proteus*, *Klebsiella*, *Pseudomonas*, *Providencia*, and *Ureaplasma urealyticum*.

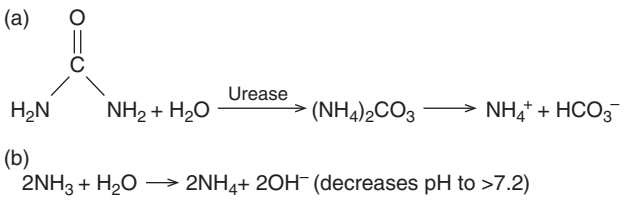

Figure 1.1.11 (a and b) Urease-producing bacteria hydrolysis of urea. $2NH_3 + H_2O \rightarrow 2NH_4 + 2OH^-$ (decreases pH to >7.2)

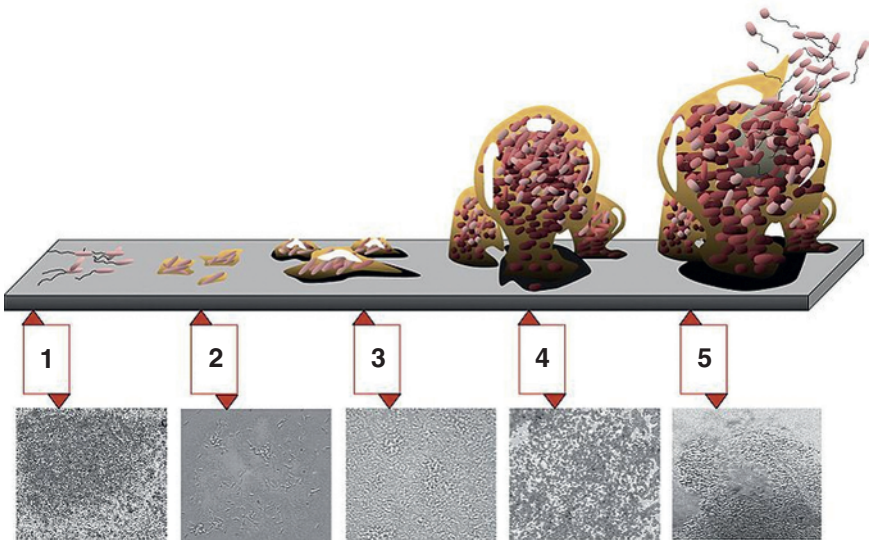

Figure 1.1.10 The five stages of biofilm development. Stage 1, initial attachment; stage 2, irreversible attachment; stage 3, maturation I; stage 4, maturation II; ND stage 5, dispersion.

Treatment is similar to recurrent UTIs in addition to acidification of urine and ensuring no encrustations or stones are left behind. For catheter bypassing not related to encrustations, bladder spasms could be the cause and are alleviated with anticholinergics.

2) Failure of balloon to deflate: can be the result of mechanical failure, encrustations around the balloon, or inexperience.
   Steps to remove catheter:
   a) Experienced doctor or nurse to attempt to deflate balloon.
   b) Inflating balloon with air or water to dislodge obstruction.
   c) Leaving 10-ml syringe firmly attached for one hour to slowly aspirate fluid from balloon.
   d) Overinflate balloon to burst it carefully because this can cause injury to the bladder.
   e) Cut end of catheter just beyond the valve might cause expulsion of the balloon fluid.
   f) In patients who are female, insert needle alongside your finger into vagina and advance through anterior vaginal wall.
   g) In patient who are male, suprapubic needle with ultrasound guidance.
   h) Pass ureteroscope alongside catheter and burst balloon with guidewire or laser fibre.
3) Allergic reaction to the catheter material, especially if latex-coated.
4) Malignancy: recurrent inflammation and irritation to the bladder can cause squamous cell carcinoma. Seen rarely in the early years 0.5% at five years, increasing to 8% over 20 years.

1.1.7 Stents

These are commonly used in endourology to bypass an obstructed drainage system or postoperatively. Drainage is thought to be around the stent; however, in complete ureteric obstruction, drainage though the stent can take place.

Classified by:

- Length: 18–30 cm long with either 1, 2, or neither end coiling.
- Size: 4.8–8 Fr.
- Material: polyurethane, polyethylene, silicone, metallic, and Memokath stents (thermos-expandable stents used in malignancy cause ureteric obstruction).
- Coating: PTFE coated or hydrogel coated.

Characteristics of an 'ideal' stent [12]:

- Good memory and does not migrate.
- Excellent flow characteristics.
- Radio-opaque.
- Biologically inert.
- Resists biofilm formation, encrustation, and infection.
- Made of a flexible material with high tensile strength.
- Easy to insert, remove, or exchange.
- Inexpensive to buy.

There is no stent that has all these features.

Indications for use in general urology:

- Electively: protection of an anastomosis, overcoming extrinsic compression, prior to chemotherapy to optimise renal function, or preoperatively to aid identification of the ureter.
- Emergency: relief of obstruction and in management of ureteric trauma.

In endourology:

- Absolute: Ureteric injury/perforation, single kidney, transplanted kidney, or high risk of residual stone obstruction.
- Relative: Oedematous ureter, long-standing impacted stone, preoperative obstruction with renal failure, balloon dilatation, ureteric cancer treatment, or biopsy.

How they work:

- Drainage is largely around the outside of the stent.
- Reflux is through the centre.
- Stones only pass very slowly alongside stent.
- Upper tract motility is reduced.
- Stents do cause partial obstruction.

1.1.7.1 Complications

Similar to catheter complications. In addition to pain and discomfort, which can be as bad as a renal stone passage, treatment is with anticholinergics, α-blockers, analgesics, or a combination of those. Furthermore, stents left in situ after stones surgery will encrust rapidly and should not be left for more than two to three weeks because can cause complete obstruction. Haematuria is common, and patients must be warned; otherwise patients will return to seek medical advice for the alarming symptom. Lost stents, migrated stents, and stent kinking causing obstruction can happen.

1.1.8 Guidewires

Guidewires are commonly used in endourology, and safe practice dictates leaving a 'safety' guidewire in situ while endoscopically operating on the upper tracts. Guidewires can also be used to aid catheterisation of the bladder, especially if multiple false passages have been created. A flexible cystoscopy leads the right path, a guidewire is left in the bladder, and a catheter railroaded over the guide wire.

Classified by:

- Length: guidewires are usually 150 cm in length.
- Size: 2.5 Fr (0.032 inches)–2.9 Fr (0.038 inches).

- Material and coating [12]: stainless steel core with PTFE coating (standard guide wires) or Nitonol (nickle-titaneum alloy) core with hydrophilic polymer coating (just the tip: Sensor guide wires; whole guide wire: Terumo guide wires) these become slippery when wet, Nitonol with PTFE coating, or stainless steel with hydrophilic polymer coating.

Expert Opinion

Though experience tends to allow for preference in use of basic urological equipment, sound knowledge of the basic science behind each technology will allow optimal usage for individual circumstances.

References

1 Nitze, M. (1877). Verander an meinen electroendoskopishen Instrumenten zur Untersuchung der mamilischen Harnblase. *Iliustr Monantschrt Artzl Polytech* 9: 59.

2 Gow, J.G. (1976). Urological technology. In: *Urology*, vol. 1 (ed. J.P. Blandy), 3–5. Blackwell Scientific Publications.

3 Hopkins HH. 1977; London: HM Patent Office. British Patent Specification No. 954629.

4 Baird JL. 1927; London: HM Patent Office. British Patent Specification No. 20969/27.

5 Hopkins, H.H. and Kapany, N.S. (1954). A flexible fibrescope using static scanning. *Nature* 173: 39–41.

6 Massarweh, N.N., Cosgriff, N.C., and Slakey, D.P. (2006). Electrosurgery: history, principles and current and future uses. *J. Am. Coll. Surg.* 202 (3): 520–530.

7 Grossweiner, L.I. (1989). Photophysics. In: *The Science of Photobiology* (ed. K. Smith), 1–45. New York: Plenum Press.

8 McNicholas, T.A., Steger, A.C., and Bown, S.G. (1993). Interstitial laser coagulation of the prostate. An experimental study. *BJU Int.* 71 (4): 439–444.

9 Bachmann, A., Tubaro, A., Barber, N. et al. (2014). 180-W XPS GreenLight laser vaporisation versus transurethral resection of the prostate for the treatment of benign prostatic obstruction: 6-month safety and efficacy results of a European multicentre randomised trial – the GOLIATH study. *Eur. Urol.* 65 (1): 931–942.

10 Tooher, R., Sutherland, P., Costello, A. et al. (2004). A systematic review of holmium laser prostatectomy for benign prostatic hyperplasia. *J. Urol.* 171 (5): 1773–1781.

11 1 French. Wolfram|Alpha. Retrieved 10.07.2016.

12 Clayman, M., Uribe, C.A., Eichel, L. et al. (2004). Comparison of guide wires in urology. Which, when, and why? *J. Urol.* 171 (6pt1): 2146.

1.2

Wound Healing in the Urinary Tract

Motaz ElMahdy Hassan[1] *and Mohamed Ismail*[2]

[1]*NHS Grampian, Aberdeen Royal Infirmary, Aberdeen, UK*
[2]*Portsmouth Hospitals, NHS Trust, Portsmouth, UK*

Abstract

Wound healing is a dynamic process that demonstrates the body's ability to respond to change in its protective integrity and maintain homeostasis by swiftly responding to this change. Wounds, either surgically or trauma induced, are a form of cellular injury that leads to a tissue response. This response is a complex process which involves the removal of necrotic tissue and induction of repair. When tissue injury occurs, the damaged blood vessels haemorrhage into the defect, platelets aggregate, and a thrombus forms. This process allows the interaction with the complement system, and inflammatory cells are attracted to the site of injury by chemotactic factors. Platelets play an essential role in this response as they release two important factors. These factors are platelet-derived growth factor (PDGF) and transforming growth factor beta (TGF-β); they are powerful chemotactic factors for inflammatory cells such as macrophages, which then migrate into the wound to phagocytose necrotic tissue and fibrin. PDGF induces the cells to change from the resting phase in G0–G1. Epidermal growth factor (EGF) and insulin-like growth factor (IGF) act to induce cell progression from G1 phase to DNA synthesis. Capillary proliferation is stimulated with angiogenic growth factors such as vascular endothelial growth factor (VEGF). The defect is repaired by capillary hyperplasia, myofibroblasts, and epithelial cells.

Nutrients and hormones play a vital role in the wound-healing process, as insulin, thyroid hormones, glucose, amino acids, and vitamin C. The deficiency in nutrients or vitamins or the presence of infection or poor local circulation may lead to delay in wound healing.

Keywords *wound healing; surgical incisions; inflammatory response; effect of urine; suture materials*

Key Points

- Wound healing is a dynamic process that manifests the concept of homeostasis as the body responds to trauma and induces healing.
- Inflammation is the cornerstone of the healing process.
- The urinary tract has unique characteristics in managing wound healing.
- Urine may interfere with wound healing and lead to:

1) Delayed healing.
2) Necrosis of the wound.
3) Contracture.

1.2.1 Introduction

Throughout history, wound healing has been a subject of interest in all the civilizations. Since the time of ancient Egyptians, 1600 BCE, the Edwin Smith surgical papyrus described the different types of wounds. The Ebers Papyrus, 1550 BCE, described the use of different materials that can be applied to the wounds (e.g. honey, grease, and lint to absorb wound discharges). Warriors and gladiators of the Roman Empire suffered a large number of injuries, and Galen, who was appointed as a physician to the gladiators, described that maintenance of moisture in the wound promoted healing.

Blandy's Urology, Third Edition. Edited by Omar M. Aboumarzouk.

For many centuries, wound healing and pathology has evolved, but the risk of infection was always a major concern. At the beginning of the nineteenth century, Semmelweis, the Hungarian obstetrician (1818–1865) found that sepsis after childbirth was much lower if the medical students attending the birth washed their hands with soap and hypochlorite. Louis Pasteur (1822–1895) proved that germs are introduced to the wounds from the environment. In 1865, Joseph Lister, who was a professor of surgery in Glasgow, read Pasteur's work and started using carbolic acid (phenol) on wounds. This has vastly reduced the rate of infection, and he then used phenol for hand washing and sterilising instruments and sprayed carbolic acid in the theatre to limit infection. This reduced the rate of infection from 50% to 15.

Gradually, the type of dressings being used evolved to encompass a wide array of customised dressings that allow variable degrees of permeability, absorbency, and antiseptic properties. Currently, wound management involves the application and manipulation of growth factors, cytokines, and bioengineered tissue [1].

1.2.2 Wound-Healing Process

The cell is a dynamic entity that maintains homeostasis despite continuous changes in the environment. When the changes are severe, cellular injury will occur. There are various mechanism of cellular injury: physical, chemical, and biological. In surgery, these three mechanisms may occur simultaneously or sequentially. A surgical incision is a form of physical injury or trauma to the tissue that may result in another form of tissue insult, such as hypoxia and predisposition to infection as a result of the breach of protective barriers. The response to injury also depends on various factors, such as, the nutritional status of the patient, blood supply to the injured area, and immunity. Previous radiation or chemotherapy may preclude an adequate response of the tissue to heal.

The response to cellular injury whether pathological as in trauma or physiological as in surgery is the same, and that is the process of inflammation. The inflammatory response is a sequential reaction to cellular injury. The mechanism of inflammation is basically the same regardless of the insulting agent. The response depends on the extent and the severity of injury and on the patient's individual response. The inflammatory response can be divided into a vascular response, cellular response, formation of exudate, and healing [2].

1.2.3 Vascular Response

After cellular injury, arterioles in the area briefly undergo transient vasoconstriction. Histamine and other chemicals are released by the injured cells leading to vasodilation. This vasodilation results in hyperaemia, which raises filtration pressure. Vasodilation and chemical mediators cause endothelial cell retraction, which increases capillary permeability that facilitates the movement of fluid from capillaries into tissue spaces, inflammatory exudate.

Exudate is composed of serous fluid that contains plasma proteins, primarily albumin, exerting an oncotic pressure that draws more fluid leading to tissue oedema. The products of the injured cells activates the plasma protein, fibrinogen, to form fibrin. Fibrin strengthens the blood clot formed by platelets. The function of the clot is to trap bacteria and prevent their spread and to serve as a framework for the healing process.

1.2.4 Cellular Response

As more fluid is lost, the blood viscosity increases, and the blood flowing through the capillaries of the injured tissue slow down. Neutrophils and monocytes move to the inner surface of the capillaries by the process of margination and then by diapedesis, which is movement by an amoeboid fashion through the capillary wall to the site of injury. Chemotaxis is the directional migration of white blood cells (WBCs) along a concentration gradient of chemotactic factors, which are substances that attract leukocytes to the site of inflammation. Chemotaxis is the mechanism for ensuring accumulation of neutrophils and monocytes at the focus of injury.

Neutrophils arrive first at the site of injury, usually within 6–12 hours; they phagocytise damaged cells, foreign material, and bacteria. To maintain the supply for the inflammatory process, the bone marrow releases more neutrophils into the circulation, and these result in an elevated WBC count. Occasionally, the demand for neutrophils increases to the extent that the bone marrow releases immature forms of neutrophils, called 'bands' or 'segmented neutrophils', into circulation. Increased numbers of band neutrophils in the circulation is called a 'shift to the left', which is commonly found in patients with acute bacterial infections. Neutrophils have a short life span of 24–48 hours. Dead neutrophils and cellular and bacterial debris accumulate and form pus.

Monocytes are also phagocytic cells that migrate from circulating blood. They are attached to the site by chemotactic factors such as mononuclear attractant protein-1 (MCP-1), fibrinopeptides, and macrophage inflammatory proteins and usually arrive at the site within three to seven days after the onset of inflammation. Monocytes transform into macrophages after arrival at the tissue spaces and phagocytose the inflammatory debris. The role of the macrophages is to clear the debris in the injured tissue before healing can occur. Macrophages have a longer life span, and as they multiply, they remain

in the injured tissue for weeks; they are instrumental in the healing process. Macrophages accumulate and fuse to form multinucleated giant cells that can engulf large particles that are too large for single macrophages. Giant cells are encapsulated by collagen and form a granuloma. This process has been classically described when tuberculosis bacillus infects the lung. As the bacillus is encapsulated, a chronic state of inflammation ensues. As the granuloma forms, the process will continue, and this cavity will contain necrotic tissue.

Each cellular component has a different role in the inflammatory process. Basophils and eosinophils have a more selective role. During an allergic reaction, eosinophils, which constitute up to 5% of the WBCs, are released in large quantities and they target organisms that are too large to be engulfed. Their mode of killing involves secreting toxic substances (e.g. reactive O_2 compounds), major basic protein, which is toxic to parasites, and several enzymes. Eosinophils also release inflammatory mediators (e.g. prostaglandins, leukotrienes, platelet-activating factor, and many cytokines).

Basophils share several characteristics with mast cells. When these cells encounter specific antigens, they undergo cellular degranulation and release preformed inflammatory mediators, such as platelet-activating factor and histamine. They also synthesise new mediators such as leukotrienes, prostaglandins, and thromboxanes. Connective tissue mast cells contain chymase, tryptase, and heparin. Through the release of these mediators, mast cells play an important role in generating a protective acute inflammatory response. The main role of lymphocytes that arrive later at the injury site is humeral and cell-mediated immunity.

The complement system plays a major role in the mediation of the inflammatory response. It contributes to increasing the vascular permeability, and enhancing phagocytosis, chemotaxis, and cellular lysis. When the complement system is activated, it works in a sequential order, which is C I, C4, C2, C3, C5, C6, C7, C8, and C9. These numbers reflect the order of their discovery. The activation of the complement system is through the fixation of the component CI to the antigen–antibody complex, which is the primary pathway. The complement is fixed by immunoglobulins IgG and IgM. When each complex is activated, it acts on the next component, hence, creating a cascade effect. In the alternative pathway; C3 is activated without prior antigen–antibody fixation [3].

1.2.5 Urinary Tract Healing

The healing process in the urinary tract after surgical intervention is slightly unique from other tissues because of the presence of urine. Due to the various surgical approaches in urological surgery, the technique involved, the location of the procedure, and the organ operated on, all contribute to the outcome of this process.

The common notion of dividing the urinary tract during surgery, which is applied in open surgery, involves division and suture of tissue. The tissue edges are bonded with fibrin, which will stimulate the growth of capillaries to form granulation tissue which will be gradually replaced by fibrous tissue, which matures to form a scar in the course of few weeks to months as a result of the remodelling process. The peculiarities of each procedure, technique, and organ involved affect the healing process. These unusual features will be discussed in the next section.

1.2.6 Different Methods of Making Surgical Incisions

In urology, there are a myriad procedures that are performed through endoscopic and minimally invasive approaches. Endoscopic surgery has replaced many conventional procedures that required open surgery and the use of the scalpel. The use of endoscopes that gradually became smaller, more robust, and provide multichannel apparatus that allows the surgeon to perform many procedures like biopsy, resection, removal of foreign body, and stone fragmentation. To provide a safe surgical environment, good visibility is essential, and hence, haemostasis and techniques for haemostasis have also evolved. Such devices include diathermy, laser technology [1], and the 'ultrasonic scalpel' [2]. To achieve ideal haemostasis, the application of thermal devices to the resected tissue will lead to a degree of tissue damage. This creates nonviable tissue that leads to more wound induration, and as the tissue has lost part of its blood supply, the sloughed tissue left behind acts as a foreign body and increases the risk of infection [3, 4].

A skin incision heals through a conventional process of granulation tissue formation which is gradually covered with an advancing film of epithelial cells that conglomerate from the wound edges by mitotic activity to close the defect [5]. In the urothelium, the process is different because this type of tissue has abundant mitoses in every layer.

The notion that all tissue defects healed the same way was defied as an unexpected finding that was reported by Brauer [6] but was largely ignored until confirmed nearly 30 years later by Johnson and McMinn [7], who found that healing in the biliary tree, the salivary ducts, and the urinary tract followed a different pattern to that of skin or intestinal mucosa. After endoscopic resection of bladder pathology, the defect is filled with the usual granulation tissue and gradually over this layer, a film of urothelium rapidly spreads because of the abundant mitotic activity in the cells that grow from the edge of the wound. This is

in contrast to the skin and bowel pattern of healing because the mitotic activity in these tissues are found some distance away from the wound edge (Figure 1.2.1).

This inwardly growing thin film of urothelium becomes thicker and eventually takes on the features of normal urothelial tissue. The agility and rapidity of urothelial growth has two important implications: (i) any cavity (such as a urinoma) which is in communication with the urinary tract may be relined with urothelium, and (ii) the regeneration of the urothelium is so rapid and effective that it can cover over and bury little islands of the original damaged urothelium.

1.2.7 Von Brunn's Nests and Metaplasia

More than 100 years ago, Von Brunn [8] described how these buried islands of urothelium would form cysts or 'nests'. More than a decade later, Giani [9], while studying the healing of transitional epithelium in dogs, observed every stage between burying of fragments of epithelium, the development of von Brunn's nests, and the formation of full-blown cystitis cystica and was able to create similar nests by implanting the vesical epithelium.

Similar epithelial growths caused by healing may occur in the skin where they give rise to innocent implantation dermoids [10]. In the urinary tract, they are peculiarly dangerous. The little nests become progressively thicker until they actually form columnar epithelium (Figure 1.2.1). In other mammals, patches of columnar mucosa are considered normal, but in humans, they are potentially malignant and are followed by the development of adenocarcinoma [11–14].

1.2.8 Squamous Metaplasia

Conditions that lead to recurrent inflammation and healing as a result of chronic irritation or infection can lead to the formation of squamous metaplasia (e.g. because of a calculus, bilharziasis, or a long-term indwelling catheter). The transitional urothelium changes into stratified squamous epithelium, which forms keratin and comes to resemble the skin, and in the presence of urine, changes into a characteristic white plaque – leucoplakia – which is a precursor for neoplasia. It must be distinguished from the innocent 'vaginal metaplasia', which is a normal feature of the trigone. The risk of malignant transformation probably varies from one site to another.

1.2.9 Heterotopic Ossification

The urothelium presents an interesting entity because a graft of urothelium placed in contact with almost any type of connective tissue may induce the formation of heterotopic bone, which is most likely to develop in the

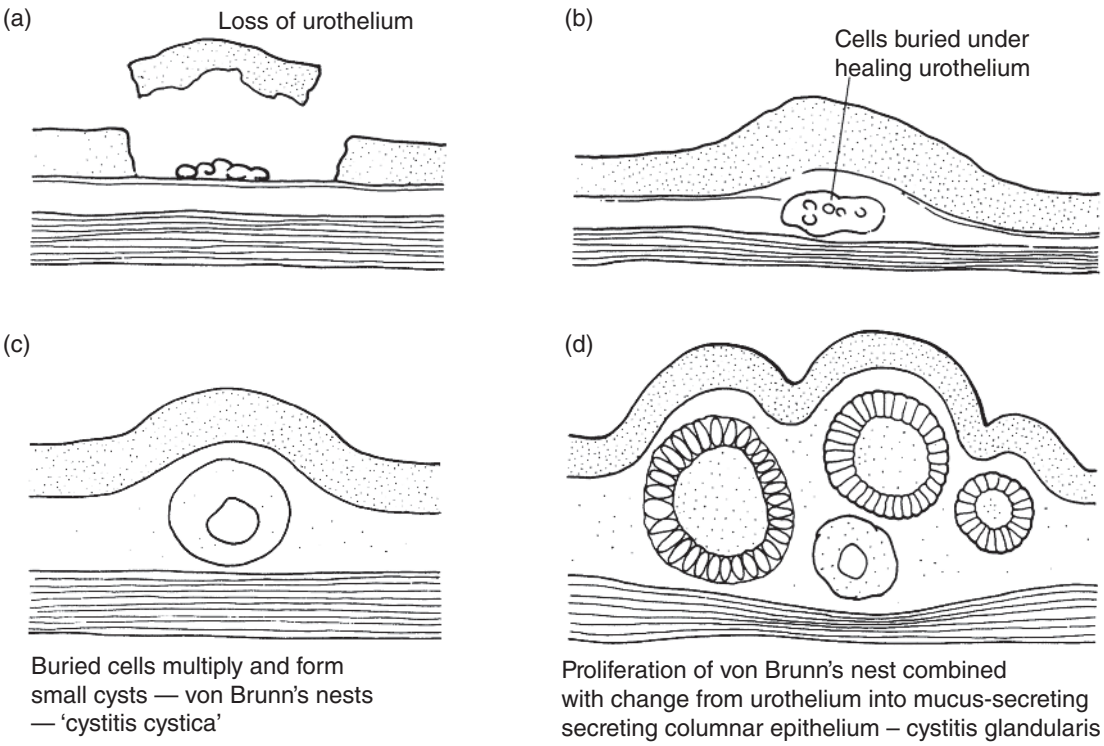

Figure 1.2.1 (a–d) A nest of cells may become buried under the healing urothelium.

vicinity of a foreign body such as a nonabsorbable suture but may be found whenever urothelium grows in an unusual site or is used as a graft (e.g. around the track of a chronic urinary fistula or around a urinoma or pseudocyst).

1.2.10 Regeneration of Smooth Muscle in the Urinary Tract

For quite some time, it has been considered that smooth muscle could regenerate across a gap in the bladder or the ureter. This was the basis for the intubated ureterotomy of Davis [15], in which a stricture in the ureter was incised and a splint was left in for six weeks and which then became surrounded by fibrous tissue, lined with a film of urothelium, and finally enclosed in smooth muscle. The same principle was considered and lay behind the idea that the bladder could regenerate after cystectomy, especially if a mould of plastic was left for it to grow over [16]. Today, it is believed that muscle does not truly regenerate but spreads in from the cut margin of the urethra [17].

1.2.11 Particular Effects of Urine

1.2.11.1 The Presence of Urine Modifies the Normal Process of Healing in the Urinary Tract

1) Prolongation of the healing process. The remodelling phase continued to the tenth day for the dermis and until the twelfth day for the urethra. It is suggested that the possible reason for the prolonged urethral wound healing is because of urine extravasation through the urethra into the surrounding tissues.
2) Necrosis**:** Urine may interfere with the healing process and may lead to tissue necrosis. An example of this manifestation is the loss of skin and subcutaneous tissue that can follow extravasation of urine after injury to the perineal urethra when the skin of the penis, scrotum, and lower abdomen may be affected and tissue damage may take place and lead to necrosis and slough formation. Also this is evident in cases of chronic urinary incontinence, when skin excoriation is noticed. The process by which urine affects the skin or tissue is not entirely clear, but it could be multifactorial as the duration of exposure, the pre-existing skin condition, the nutritional status of the individual, and factors in the composition of urine itself (e.g. hyperosmolarity, alkaline, or acidic pH) and secondary infection. The subcutaneous injection of almost any fluid that is markedly hypertonic, acid, or alkaline is well known to give rise to pain and inflammation, and in practice even if infection is not present at first, because the tissue is damaged by inflammation, infection may inevitably follow.

   The extravasation of urine, for example, after cystectomy may lead to necrosis of the momentum and delay the healing process at the anastomotic sites. It may also lead to tissue breakdown and formation of fistulas (e.g. enterocutaneous fistulas).
3) Contracture: The effect of urine by causing contracture formation on scar tissue is an important issue. All scars contract to some extent, and contracture in scars which cross joints is a common problem that may affect joint mobility. In the urinary tract, as the healing process continues through tissue remodelling, the sites of anastomosis could be affected by stricture formation. Urine exacerbates the tendency for scars to contract. When urine is diverted from the site of an injury to the urethra, the formation of a stricture may be prevented. Taking this notion into consideration, surgical technique can have an impact on this process so as to avoid the effect of scar tissue and stricture formation; however, considerable ingenuity in planning the anastomotic technique in the urinary tract is essential. The anastomosis can be designed in the form of a long elliptical shape so that even after healing and scar-tissue formation, the lumen would still be adequate for maintaining drainage (Figure 1.2.2).

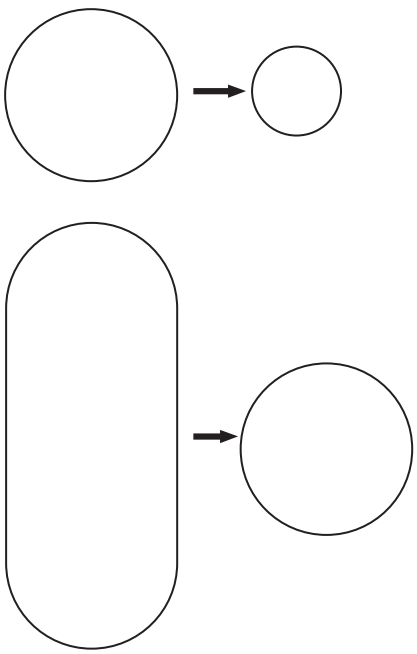

Figure 1.2.2 To avoid stenosis, all anastomoses in the urinary tract are designed as an ellipse so that there will still be an adequate lumen even after contracture has taken place.

1.2.12 Suture Materials, Splints, Meshes, and Films

1.2.12.1 Suture Materials

There are different types of suture material and are classified into absorbable or non-absorbable and monofilament or braided (multifilament) (Table 1.2.1). Commonly used absorbable sutures are synthetic, whereas the non-absorbable can be natural or synthetic.

The absorbable sutures are broken down by phagocytes and are hydrolysed with no remaining material and vary depending on the length of time it takes the body to absorb the material: 30–40 days, 50–70 days, or > 100 days (Table 1.2.1). Nonabsorbable sutures will remain for a long time in the wound, and although they will eventually break up, residual foreign matter will remain in the tissue (e.g. Ethibond and Prolene). This remaining material may harbour microorganisms which may hinder phagocytosis or the action of antimicrobials and lead to wound infections or chronic infection, or they may get calcified.

There is a risk of sinus formation when nonabsorbable sutures are used during infection; hence, they are avoided in infection-related procedures such as a nephrectomy of pyonephrosis.

When nonabsorbable sutures are chosen during surgery, one must bear in mind that monofilament sutures have the advantage over braided or twisted ones because they have a smaller surface area and no interstices which may harbour bacteria. This may reduce the risk of infection, although it cannot be eliminated entirely.

In the urinary tract, if a nonabsorbable suture is exposed to urine, it is almost inevitable that stones will form. There is also risk of stone formation even if absorbable sutures are used; however, it is significantly less than with nonabsorbable sutures [18, 19]. Even the most inert of metals (e.g. haemostatic clips) can cause stones to form [20]. Sutures placed right outside the urinary tract may, in the course of time, work their way like a cheese wire through living tissue until they come to lie within the urinary tract.

The tendency to form calculi does not seem to be related to the amount of histological reaction generated in the tissues. Even the most histologically inert materials (e.g. polyurethane, silicone, and hydrogels used for manufacturing double-J stents) may be affected by encrustation and stone formation with deleterious consequences.

1.2.12.2 Synthetic Absorbable Suture Materials

The synthetic absorbable suture material made of polyglycolic acid (PGA) or polyglactin (a copolymer of glycolide and lactide) provokes less inflammatory response. The breakdown of these sutures is a result of chemical

Table 1.2.1 Suture types, material, and absorption time.

	Material	Absorption time (days, strength retention)
Absorbable multifilament		
Vicryl	Polyglycolic acid polymer	56–70 (75% at 2 weeks, 50% at 3 weeks, and 25% at 4 weeks)
Vicryl rapide	Polyglycolic acid polymer	30–40 (75% at 2 weeks, 50% at 3 weeks, and 25% at 4 weeks)
Absorbable monofilament		
Monocryl	Poliglecaprone	90–120 (60% to 70% at 1 week 30% to –40% at 2 weeks)
PDS	Polydioxanone	18–240 (3.0 : 80% at 2 weeks, 70% at 4 weeks, 60% at 6 weeks; 4.0 : 60% at 2 weeks, 40% at 4 weeks, 35% at 6 weeks)
Synthetic nonabsorbable multifilament		
Ethibond	Polyester	
Mersilene	Polyester/Dacron	
Nurolon	Nylon	
Synthetic nonabsorbable monofilament		
Ethilon	Nylon	
Prolene	Polypropylene	
Pronova	Polyvinylidene fluoride	
Natural nonabsorbable multifilament	Perma-hand (silk)	
Natural nonabsorbable monofilament	Stainless steel (metallic)	

hydrolysis rather than biological phagocytosis. These sutures are relatively strong for their size and maintain their tensile strength long after the healing process and the tissue has reached its maximum tensile strength.

When absorbable sutures are used in the urinary tract, they have two possible disadvantages: (i) The suture may take a considerable period of time to hydrolyse and as it is in contact with urine, there is a chance that a stone may form; and (ii) urine may accelerate the hydrolysis of the suture material, especially in the presence of a *Proteus* infection [21, 22].

1.2.12.3 Meshes

Meshes are frequently used in urology to treat stress urinary incontinence and pelvic floor prolapse. It can be classified into synthetic or biological meshes. Synthetic meshes can be absorbable or non-absorbable. Absorbable mesh is made of polyglactin (Vicryl) or polyglycolic (Dixon). Nonabsorbable mesh is made of polypropylene and mostly used in urological procedures because of their durability and strength.

The most important characteristic of synthetic mesh is pore size [23]. Synthetic meshes are classified according to their pore size into macroporous (>75 µm) and microporous (<10 µm) (Table 1.2.2). Macroporous mesh allows immune cells to travel through mesh structure and reduce risk of infection. It also incorporates well into the host tissue by promoting higher ratio of type I/III collagen [24].

A mesh originally used to support bladder neck is placed outside the urinary tract; however, it may migrate through the tissues into the urinary bladder causing chronic pain, urinary tract infection, and overactive bladder syndrome.

Biological meshes are primarily made of organic material of human, bovine, or porcine in origin such as dermis or pericardium. Biological mesh is treated to acellular extracellular matrix composed mainly of collagen with additional elastin and laminin. Growth factors within the mesh attract fibroblast. The three-dimensional architecture and porosity of the mesh allow structural cells to enter the mesh and adhere to it. The mesh eventually degrades and is replaced with a collagen scaffold of the host tissue in a process called 'remodelling' [25].

Table 1.2.2 Mesh types, characteristics, and material.

Mesh type	Characteristics	Material
Type I	Macroporous prostheses (pores >75 µm)	Prolene
Type II	Microporous prostheses (pores <10 µm)	Gore-Tex
Type III	Macroporous prostheses with microporous components	Teflon
Type IV	Submicronic pore size	Silastic

1.2.12.4 Injectable Agents

Injectable agents are used to treat stress urinary incontinence and vesicoureteric reflux. Polytetrafluoroethylene (PTFE, or Teflon) was first introduced in 1973 [26]. More recently, various agents have been used as a bulking agent. Injectable bulking agents can be classified into biological or synthetic. The most commonly used biological agents are collagen. Synthetic agents that are currently in use include hyaluronic acid dextranomer (Deflux) and polyacrylamide hydrogel (Bulkamid). The ideal injectable agent should be easy to prepare and inject, biocompatible, non-imunogenic, non-carcinogenic, and does not contract with time [27]. Glutaraldehyde cross-linked (GAX) collagen bulking agent has been demonstrated to be safe and efficacious in the short and intermediate term [28]. After injection, it attracts host immune cells and fibroblasts and encourages neovascularisation. Ultimately, the remodelling process results in the replacement of the injected collagen with the patient's own type I and III collagen [29].

Expert Opinion

- The urinary tract has unique characteristics because of the presence of urine and during surgical procedures; attention to this fact is essential as urinary diversion could be essential to allow wound healing in some situations.
- Surgery is a controlled induced trauma, and various elements of the procedure could either enhance or affect wound healing and recovery.
- During surgery, attention to good aseptic technique, haemostasis, judicious use of electrocautery, and good tissue approximation could enhance recovery and healing.
- In elective major procedures, such as cystectomy and urinary diversion and radical and partial nephrectomy, enhancing the patient's physiological status through advice on smoking cessation, weight loss, exercise and good nutrition, and good control of diabetes and hypertension may lead to a favourable and enhanced postoperative course and recovery.
- Wound healing occurs in stages, and understanding the intricacy of each stage and how trauma or surgery may affect this process may help in better management of wounds.

References

1 Broughton, G. 2nd, Janis, J.E., and Attinger, C.E. (2006). A brief history of wound care. *Plast. Reconstr. Surg.* 117 (7 Suppl): 6S–11S.

2 Eming, S.A., Krieg, T., and Davidson, J.M. (2007). Inflammation in wound repair: molecular and cellular mechanisms. *J. Investig. Dermatol.* 127 (3): 514–525.

3 Koh, T.J. and DiPietro, L.A. (2011). Inflammation and wound healing: the role of the macrophage. *Expert Rev. Mol. Med.* 13: e23.

4 Beisland, H.O. and Sander, S. (1990). Neodymium-YAG laser irradiation of stage T2 muscle-invasive bladder cancer. Long-term results. *Br. J. Urol.* 65 (1): 24–26.

5 Boddy, S.A., Ramsay, J.W., Carter, S.S. et al. (1987). Tissue effects of an ultrasonic scalpel for clinical surgical use. *Urol. Res.* 15 (1): 49–52.

6 Brauer, A. The regeneration of transitional epithelium. *Anat. Rec.* 1927 (33): 137.

7 Johnson, F.R. and McMinn, R.M. (1956). Transitional epithelium and osteogenesis. *J. Anat.* 90 (1): 106–116.

8 Av, B. (1893). Ueber drusenahnliche Bildungen in der Schleimhaut des Nierenbeckens, des Ureters, und der Harnblase beim Menschen. *Arch. Mikrosk. Anat.* 41: 294.

9 Giani, R. (1907). Neuer experimenteller Beitrag zur Entstehung der Cystitis Cystica. *Beitr. Path. Anat.* 42: 1.

10 Gillman, T., Penn, J., Bronks, D., and Roux, M. (1953). Reactions of healing wounds and granulation tissue in man to auto-Thiersch, autodermal, and homodermal grafts: with an analysis of the implications of the phenomena encountered for an understanding of the behaviour of grafted tissue and the genesis of scars, keloids, skin carcinomata, and other cutaneous lesions. *Br. J. Plast. Surg.* 6 (3): 153–223.

11 Johnson, F.R. (1957). Some proliferative and metaplastic changes in transitional epithelium. *Br. J. Urol.* 29 (2): 112–120.

12 De La Pena, A., Oliveros, M., Tamames, J.M., and Mintz, S. (1959). Metaplastic and malignant changes of the urothelium. *Br. J. Urol.* 31: 473–478.

13 Cea, P.C., Ward, J.N., Lavengood, R.W. Jr., and Gray, G.F. (1977). Mesonephric adenocarcinomas in urethral diverticula. *Urology* 10 (1): 58–61.

14 Navarre, R.J., Loening, S.A., Platz, C. et al. (1982). Nephrogenic adenoma: a report of 9 cases and review of the literature. *J. Urol.* 127 (4): 775–779.

15 Davis, D.M., Strong, G.H., and Drake, W.M. (1948). Intubated ureterotomy; experimental work and clinical results. *J. Urol.* 59 (5): 851–862.

16 Bohne, A.W., Osborn, R.W., and Hettle, P.J. (1955). Regeneration of the urinary bladder in the dog, following total cystectomy. *Surg. Gynecol. Obstet.* 100 (3): 259–264.

17 Swinney, J., Tomlinson, B.E., and Walder, D.N. (1961). Urinary tract substitution. *Br. J. Urol.* 33 (4): 414–429.

18 Holmes, S.A., Miller, P.D., Crocker, P.R., and Kirby, R.S. (1992). Encrustation of intraprostatic stents–a comparative study. *Br. J. Urol.* 69 (4): 383–387.

19 Morris, M.C., Baquero, A., Redovan, E. et al. (1986). Urolithiasis on absorbable and non-absorbable suture materials in the rabbit bladder. *J. Urol.* 135 (3): 602–603.

20 Miedema, E.B. and Redman, J.F. (1982). Case profile: radiolucent urethral calculus with hemostatic clip nidus. *Urology* 19 (3): 328.

21 el-Mahrouky, A., McElhaney, J., Bartone, F.F., and King, L. (1987). In vitro comparison of the properties of polydioxanone, polyglycolic acid and catgut sutures in sterile and infected urine. *J. Urol.* 138 (4): 913–915.

22 Schiller, T.D., Stone, E.A., and Gupta, B.S. (1993). In vitro loss of tensile strength and elasticity of five absorbable suture materials in sterile and infected canine urine. *Vet. Surg.* 22 (3): 208–212.

23 Amid, P.K., Shulman, A.G., Lichtenstein, I.L., and Hakakha, M. (1994). Biomaterials for abdominal wall hernia surgery and principles of their applications. *Langenbecks Arch. Chir.* 379 (3): 168–171.

24 Brown, C.N. and Finch, J.G. (2010). Which mesh for hernia repair? *Ann. R. Coll. Surg. Engl.* 92 (4): 272–278.

25 Steve Payne, I.E., Ian Eardley, G.G., and O'Flynn, K. ed. (2012). *Imaging and Technology in Urology: Principles and Clinical Applications*. London: Springer-Verlag.

26 Berg, S. (1973). Polytef augmentation urethroplasty. Correction of surgically incurable urinary incontinence by injection technique. *Arch. Surg.* 107 (3): 379–381.

27 Kershen, R.T. and Atala, A. (1999). New advances in injectable therapies for the treatment of incontinence and vesicoureteral reflux. *Urol. Clin. N. Am.* 26 (1): 81–94. viii.

28 Kerr, L.A. (2005). Bulking agents in the treatment of stress urinary incontinence: history, outcomes, patient populations, and reimbursement profile. *Rev. Urol.* 7 (Suppl 1): S3–S11.

29 Frey, P., Lutz, N., Berger, D., and Herzog, B. (1994). Histological behavior of glutaraldehyde cross-linked bovine collagen injected into the human bladder for the treatment of vesicoureteral reflux. *J. Urol.* 152 (2 Pt 2): 632–635.

1.3

Simulation in Urology

Hamid Abboudi[1,2], Muhammad Shamim Khan[1,2,3], Prokar Dasgupta[1,2], and Kamran Ahmed[1,2]

[1]*MRC Centre for Transplantation, King's College London, King's Health Partners, London, UK*
[2]*Department of Urology, Guy's & St. Thomas' Hospital, London, UK*
[3]*Guy's & St. Thomas' Hospital, NHS Foundation Trust, King's College, London, UK*

Abstract

Surgical simulation can be traced as far back as ancient India, where the first notion of using cadavers and synthetic models for practice prior to surgery spawned. In modern surgical practice, the advancements in science and technology have led to the introduction of new surgical technologies as well as more challenging surgical procedures for a more complex patient population. Limitations in surgeons' working hours and increased emphasis on utilising costly resources more efficiently have posed challenges to surgical educators. Fundamentally and most importantly, simulation training provides a platform for safe surgical education without compromising patient safety. Simulation has the potential to provide a time-efficient, cost-effective, and safe method of training. Furthermore simulated scenarios provide a means to develop nontechnical, safe, and effective teamwork skills that have been shown to influence patient outcomes. As such, there is growing interest in establishing simulation curriculums and assessment methodology with associated integration within urology training programmes to aid in the acquisition of both technical and nontechnical skills required for safe, modern urological practice.

Keywords *simulation training; virtual-reality simulation*

Key Points	
This section covers the following topics:	• Simulation modalities • Simulation in urology
• History of simulation	

1.3.1 Introduction

The traditional Halsted model of surgical training, 'see one, do one, teach one', has become increasingly difficult to implement. The introduction of new surgical technologies has been accompanied by more challenging surgical procedures for a more complex patient population. In addition, reduction in working hours, fear of litigation, outcome reporting, and pressures to utilise costly operating room (OR) resources more efficiently have led to significant changes in the curricula for surgical training.

Recognising modern changes to surgical practice, surgical simulation has evolved over the last two decades as an education tool that seeks to bridge the gap between the initial phases of a procedural learning curve and the OR. The aim of simulation is to aid the acquisition of specific skills and improve both competence and confidence. Simulation training provides a safe environment for repetitive practice of different surgical skills free from risk of harm to patients and a means of providing trainees with immediate feedback and the opportunity to train to a predetermined expert proficiency. This is exemplified by the theory of 'deliberate practice' [1], which dictates that to achieve 'expertise', multiple repetitions of a skill and the provision of constructive feedback to ensure the skill is being learned correctly is required. Surgical simulation provides the trainee with an opportunity to repeatedly perform a specific skill, or set of

Blandy's Urology, Third Edition. Edited by Omar M. Aboumarzouk.

skills, in a low-risk environment away from patients, thus allowing for a safe environment where mistakes can occur. The trainee is then able to learn how to correct mistakes, problem solve, and develop the confidence to deal with complications when they occur in real-world settings without it being experienced for the first time. Furthermore, simulation allows the trainer to provide timely and constructive formative or summative feedback based on trainee performance, ensuring acquisition of competency.

1.3.2 History of Simulation in Medicine

Surgical simulation has been around long before complex, high-fidelity, virtual-reality devices were developed. Traditional basic surgical skill training was done on oranges to practise suturing skills or on a table leg for surgical knots. Currently, synthetic models have greatly improved in look, feel, and tactile behaviours, and many medical device companies now produce a range of general and specialist surgical skills models from high-fidelity materials. However, the earliest contribution to the field of surgical simulation was by the ancient Indian surgeon, Sushruta Samhita [2]. He advocated the use of cadavers and synthetic models for practice prior to surgery. He taught technical skills using experimental models that included probing on worm-eaten wood and incising vegetables, such as watermelons and cucumbers. The first modern skills 'simulator' was produced in 1928 when Edwin Link created a pilot trainer, which allowed trainee pilots to learn important aeronautical manoeuvres whilst remaining on the ground, making learning to fly cheaper, safer, and more accessible. By the end of World War II in 1945, there were 6271 Link Trainer simulators in circulation [3]. One of the earliest examples of medical simulation was a foetal and human pelvis bone model used by Madame du Coudray to train midwives in eighteenth-century France [4]. In 1960, the first medical simulator, a resuscitation training manikin was developed when a girl drowned in the River Seine in Paris. This model, initially created by the toy maker Asmund S. Laerdal, has now become the Resusci Anne, which is still widely used today by first aid and life support courses to teach mouth to mouth resuscitation and airway and breathing assessments. In the 1960s, Abrahamson and Denson developed the Sim One, resuscitation trainer. This could simulate breathing, heart rate, pulses, and blood pressure and had eyes and a mouth that could open and close. Further developments in high-fidelity simulators had to wait until the 1980s. The Comprehensive Anaesthetic Simulation Environment (CASE) and the Gainesville Anaesthetic Simulator (GAS) utilised concepts developed by the aviation industry to teach anaesthetic crisis management using team-based simulated scenarios. Modern high-fidelity training focuses on the technical and nontechnical skills (NTS) required to make a safe, effective surgeon and also add a realistic environment for simulations.

In 1989, the US computer scientist Jaron Lanier took the concept of *virtual*, describing something that appeared to exist without actually existing, and combined it with the term 'reality', meaning something that is observable and measurable as opposed to the imaginary or delusional [5]. Virtual-reality (VR) surgical simulators began to grow in the 1990s beginning with lower limb reconstruction simulator (Delph et al.) to the late 1990s where a range of operations could be catered for by this technology. Evidence for its safety and effectiveness began to emerge; in particular, Seymour et al. showed that trainees could significantly reduce their procedure times to perform a cholecystectomy by 29% and were five times less likely to injure the gallbladder after using a VR trainer [6]. In 2004, the US Food and Drug Administration approved the introduction of the VR carotid stent procedure into their training programme. For the first time, trainees had to prove themselves on a competency-based task to be allowed to perform a human procedure [7]. With the development of web-based simulations, such teaching modalities are becoming cheaper and more accessible. However, the future of surgical education does not solely lie with one form of simulation, but in the combination of different modalities integrated into the curriculum.

1.3.3 Simulation Modalities

Surgical simulator training can be separated into four broad categories: physical (mechanical) simulators, animal, cadaveric, and virtual reality (VR). Physical simulator models range from part task trainers (e.g. laparoscopic box trainers) to procedure-specific trainers (e.g. ureteroscopy trainers). These are often more suitable to novice or intermediate trainees. Because of the lack of clinical variability and the inability to provide individualised proficiency-based variations in complexity, inanimate surgical simulation models often decrease in utility for advanced-level training. Animal and cadaveric surgical training has more significant cost and ethical and legislative implications; however, this is offset by providing improved contextual fidelity and opportunities to practise a whole procedure. To maximise this finite resource, it is paramount that animal-model training forms part of a well-designed, comprehensive curriculum with clear learning objectives.

VR simulators have been the mainstay of training in aviation and nuclear industries for decades, being utilised for teaching, evaluation, certification, and recertification purposes. Tasks are performed on a computer-based

platform and artificially generated virtual environment. Improvements in computer processing have led to more realistic and sensitive VR simulators, which are now capable of providing statistical feedback on the surgeon's performance, a quality that is not shared by mechanical or cadaveric simulator trainers. This feature also eliminates the need for expert faculty present during the entirety of training and promotes a self-directed learning environment. The improvements in modern software allow for clinical variations to be built into the simulator, improving the training content delivered. VR simulators have been validated as a training tool with shown educational impact and content, context, and construct validity [8]. The main challenge to programme directors has been justifying the steep costs because little data currently shows any cost effectiveness.

Simulation training also encompasses simulated clinical scenarios such as mock OR team-training sessions. These high-fidelity facilities are used in the development and assessment of crisis management skills and nontechnical skills (NTS) training such as leadership, management, and communication. With the majority of surgical errors as a result of poor communication [9], increasing attention has been directed towards simulated OR facilities to improve pre-, intra-, and postoperative communication between the surgical multidisciplinary team.

1.3.4 Simulation in Urology

Urology remains at the forefront of surgical innovation, particularly in the field of minimally invasive surgery, which includes endoscopy, laparoscopy, and robotics. As the nature of practice is changing, so are the definitions and requirements of competency [10]. Fundamental to this change in practise is patient safety, which must not be compromised. A competent urologist must have a plethora of attributes to practice in the modern surgical environment including excellent technical, team-working, communication, leadership, and decision-making skills. Urology has embraced simulation training, both in its development and application.

1.3.5 Endourology Simulation

Over the last few decades, the applications of endoscopic techniques have expanded. The development of ureterorenoscopy (URS) and percutaneous nephrolithotomy (PCNL), superseding open stone surgery, and novel bladder outflow obstruction (BOO) techniques challenging the gold standard transurethral resection of the prostate (TURP), such as Holium enucleation and Green light laser, are growing. This has necessitated the concomitant need for training and qualification in the established and newer techniques. In response to this demand, there have been a range of endourological simulators focusing on core procedures, including urethrocystoscopy, URS, transurethral resection of a bladder tumour (TURBT), TURP, and percutaneous access (Table 1.3.1). The most extensively studied models are the URO Mentor (Simbionix); a computer-based VR model offering semi-rigid and flexible urethrocystoscopy and URS modules and the Uro-Scopic trainer (Limbs & Things, Bristol UK), a high-fidelity bench model permitting use of real OR instruments in urethrocystoscopy and URS. Three prospective randomised controlled trials have supported these two ureteroscopy simulators in terms of face, content, and construct validity, with training on the URO Mentor showing improvements in surgical performance in the OR [11–14]. There are only two available simulators for TURBT training, with few validation studies. This may be related to difficulties in developing simulators that can encompass the variation of tumours in patients. Eight TURP, nine URS, eight urethrocystoscopy, and nine percutaneous access models have been developed. Universities have developed the majority of these, in particular the TURP and percutaneous access models, while ureteroscopy simulation has received greater interest from the industry.

Limitations in endourological-simulator validity studies relate to small participant numbers and the use of time as the objective parameter to assess competency. Although time is an easy parameter to measure, it is not necessarily a sign of competency, and more focus is required to objectively measure outcomes and the various steps within a procedure. For example, TURP parameters should include volume of prostate resected, blood loss, and associated injuries such as ureteric orifice or sphincter damage. With the majority of endourological simulator literature in the form of descriptive texts as opposed to validity studies, coupled with the lack of randomised controlled studies, none of the urology training models described and researched can be said to have proven validity for use in specialty training. There is also a lack in the development and research of simulation devices that focus on novel bladder outflow obstruction procedures such as Green Light Laser and Holium Enucleation.

1.3.6 Laparoscopy Simulation

There are two laparoscopic urology simulators that have undergone validation studies: Procedieus MIST VR (Mentice) and the LAP mentor (Symbionix) (Table 1.3.2). Currently these platforms have only been developed and researched for training in laparoscopic nephrectomy (LN). Wijn et al. assessed the construct validity of the LN VR simulator (Mentice, Gothenburg, Sweden) [15].

Table 1.3.1 Endourology simulators and there validation.

Procedure	Simulator type	Description of simulator	Face, content, and construct validity demonstrated	Evidence of skills transfer to the OR
Urethrocystoscopy	VR	URO Mentor (Symbionix)	Yes	
		URO trainer	Yes	
		George Washington University Medical Center, Washington, DC, US	Content only	
		Storz	Content and Construct	
	Bench	Limbs & Things	No	
		Mediskills	No	
	Organic: pumpkin, green pepper	Southern Illinois University School of Medicine, Springfield, IL, US	No	
	Animal, porcine liver in pumpkin	Southern Illinois University School of Medicine, Springfield, IL, US	No	
Ureterorenoscopy	VR	URO mentor (Symbionix)	Yes	Yes
		Duke University Medical Center, Durham, NC, US		
	Bench	Limbs and things	Yes	
		Mediskills	Yes	
		University Toronto model	Yes	
	Animal, porcine kidney	Klinikum Coburg, Germany	No	
		Southern Illinois University School of Medicine, Springfield, IL, US	No	
		University of California, Irvine, CA, US	No	
	Human, uterus	University Medical Center, Shreveport, LA, US	No	
TURP	VR	Pelvic vision	Yes	Yes
		UW TURP trainer	Yes	
		University College, London, UK	Yes	
		University of Washington, Seattle, WA, US	No	
		University Hospital Linkoping, Sweden	Content and Construct	
		Imperial College of Science, Medicine, London, UK	No	
	Bench	Limbs & Things	No	
	Animal, canine cadaver	University of California, CA, US	No	
TURBT	VR	URO Mentor (Symbionix)	Yes	
		Storz	Content and Construct	
	Bench	Limbs and things	No	
PCNL	VR	PERC mentor (Symbionix)	Yes	
	Bench	Limbs and things	No	
		Mediskills	No	
		University Hospital of Tours, Tours, France	No	

Table 1.3.1 (Continued)

Procedure	Simulator type	Description of simulator	Face, content, and construct validity demonstrated	Evidence of skills transfer to the OR
	Animal, porcine kidney	Petropolis School of Medicine, Rio de Janeiro, Brazil	No	
		Klinikum Coburg, Germany	No	
		Southern Illinois University School of Medicine, Springfield, IL, US	No	
		Medicine, Springfield, IL, US	No	
		University Hospital Mannheim, Germany	No	

PCNL, percutaneous nephrolithotomy; TURBT, transurethral resection of a bladder tumour; TURP, transurethral resection of the prostate; VR, virtual reality.

Table 1.3.2 Laparoscopy simulators and there validation.

Procedure	Simulator type	Description of simulator	Face, content, and construct validity demonstrated	Evidence of skills transfer to the OR
Laparoscopic nephrectomy	VR	Procedicus MIST (Mentice)	Yes	
		LAP mentor (Symbionix)	Yes	
General laparoscopic skills	Physical	eoSim Laparoscopic simulator (eo Surgical)	Yes	
		LapSim (Limbs and Things)	Yes	
		Pyxus HD (inovus)	No	
		iSIm2 (iSurgicals)	No	
		FLS Laparoscopic Trainer (Venture Technologies Inc.)	Yes	

VR, virtual reality.

A total of 21 novice, 32 intermediate, and 10 experienced urologists performed the same retroperitoneal task on the LN VR three times each. In regard to outcomes, including time, blood loss, path length (distance of displacement of all instruments in m), and total score, the LN VR simulator could not distinguish between intermediate and experienced participants. Wijn et al. concluded that the simulator did not have sufficient construct validity. Brewin et al. evaluated the face, content, and construct validity of the Procedicus MIST™ nephrectomy simulator [16]. Face validity was established by eight expert laparoscopic surgeons, who believed that the simulator was a good training tool. Content validity was established by the experts, who rated the simulator as above average for realism. Construct validity was verified after performance results were analysed. Experts completed nephrectomy simulation significantly faster than novices with fewer errors and less haemorrhage and tool travel (Mann–Whitney U test $p < 0.05$).

The European Association of Urology (EAU) has also recognised the importance of simulation training in overcoming the initial learning curve in laparoscopic surgery and consequently developed the programme for laparoscopic urological skills (PLUS). The PLUS examination offers quality criteria and time criteria for the completion of basic laparoscopic tasks including peg transfer, cutting a circle, single knot tying, clip and cut, and needle guidance. This programme has been proven for face, content, and construct validity by a cohort of laparoscopic experts, intermediates, and novices in the Netherlands [17]. As a result, PLUS has been implemented at a national level in the Netherlands as a basic laparoscopy examination. The EAU have extended the programme further by developing the European Basic Laparoscopic Urology Skills Course [18], a combination of theory and practical assessments that aim to provide a basic level of laparoscopic competency prior to embarking on live training. Full validation is still awaited.

Similar to endoscopic simulators, there is a lack of prospective randomised controlled trials investigating the translational benefit of laparoscopic simulators to the OR. The majority of laparoscopic simulation research has focussed on LN procedures. With the expanding role of laparoscopic partial nephrectomy, pyeloplasty, cystectomy, and prostatectomy, future laparoscopic simulation development and research must keep pace.

1.3.7 Robotic Surgery Simulation

Since its first application in 2000 by Binder and Kramer, the uptake of robotic surgery has been rapid. This ever-evolving surgical technique has cemented itself as the gold standard for the removal of the prostate gland. There are six commercially available robotic simulators all of which are VR platforms (Table 1.3.3): Robotic Surgical Simulator (RoSS™), SimSurgery Educational Platform (SEP), ProMIS®, Mimic dV-Trainer (MdVT), Surgical SIM RSS, and the da Vinci® Skills Simulator™ (dVSS) (Figure 1.3.1). The biomechanics lab at the University of Nebraska at Omaha have also developed their own VR simulator. These platforms aim to establish the basic principles of robotic operative techniques, namely, endowrist manipulation, camera and clutching, needle control and driving, energy, and dissection control. In terms of validation, all of the simulators except RoSS have demonstrated face, content, and construct validity, but the numbers in these studies remain small. Educational impact has been shown in studies and in all commercially available simulators except SEP. Evidence of criterion validity, such as predictive or concurrent validity, is sparse. Other parameters, such as inter-rater and inter-item reliability, feasibility, acceptability, and cost effectiveness of the simulation platforms were not evaluated by any of the studies. Similarly no group has validated the use of animal models and freshly frozen cadavers and structured skills training based on observation for robotic surgery. There is a distinct lack of comparative studies between the different simulators. The current body of evidence does not identify any one simulator being more effective in training the next generation of robotic surgeons than another. Each platform has the capability to train and assess a range of different robotic skills fundamental to the technique. Unlike the dVSS, the MdVT and RoSS platforms have user interfaces that are similar to, but not exact duplicates of, the dVSS console used in clinical practice. The ProMIS simulator enables virtual and physical reality to be used together and has been investigated in the laparoscopic setting previously. A randomised control trial by Feifer et al. represents the highest level of evidence for any of the simulators currently available [19]. Their study showed that the use of ProMIS and LapSim simulators in conjunction with each other could improve robotic console performance. Interestingly, the LapSim group showed no improvement, and it was therefore not clear what contribution LapSim had on the overall improvement seen when both simulators were used in conjunction. Despite SEP's level of validation, its biggest disadvantage lies in the fact that the images are not three dimensional (3D), a fundamental concept pertaining to robotic compared with laparoscopic surgery. Further studies or perhaps even hardware upgrades to convert the two-dimensional (2D) simulator into a 3D platform are therefore warranted.

The majority of robotic surgical simulators focus on prostatectomy training. There is an ever-growing role for robotic cystectomy, radical nephrectomy, and partial nephrectomy. As such, current simulators will require software updates, and in future simulator, developers will need to consider these advances in their designs.

Table 1.3.3 Robotic simulators and their validation.

Procedure	Simulator type	Description of simulator	Face, content, and construct validity demonstrated	Evidence of skills transfer to the OR
Robotic surgery: generic skills and prostatectomy	VR	dV-trainer (Mimic)	Yes	Tissue
		dVSS (Intuitive Surgical)	Yes	
		RoSS (simulated surgical systems)	Face and Content	
		SEP (Sim Surgery)	Yes	
		ProMIS (CAE healthcare)	Yes	
		Surgical SIM RSS (METI)	Yes	
Partial Nephrectomy	Bench		No	

VR, virtual reality.

Figure 1.3.1 Virtual reality robotic simulators. (a) SEP, (b) RoSS, (c) ProMIS, (d) MdVT, (e) dVSS.

1.3.8 Nontechnical Skills Simulation

NTS can be classified into cognitive factors (e.g. decision making, situational awareness), social factors (e.g. communication, teamwork, leadership), and personal resource factors (e.g. ability to cope with stress and fatigue) [20]. These NTS and related behaviours specifically affect performance in the OR. Studies have also developed validated scoring systems such as The Oxford Non-Technical Skills score (NOTECHS) and Non-technical Skills for Surgeons (NOTSS) (Table 1.3.4) that can be used for research, to provide feedback during training, and to provide an educational framework to describe these skills to surgeons [21, 22]. Research in medicine and other safety critical industries (e.g. aviation, nuclear power, and military) has shown that training can improve NTS and team performance in the workplace. Several strategies have been used to improve NTS, but in surgery, as in other industries, simulation-based team training has emerged as one of the best ways to achieve this.

Team-based training typically uses high-fidelity simulated environments to represent clinical scenarios. Simulated OR scenarios can be developed by combining a high-fidelity human patient manikin with a part task surgical trainer in a simulated OR environment (Figure 1.3.2). Modern manikins can reproduce realistic patient physiology, while a part-task surgical simulator simulates a technical aspect of the procedure. Careful attention to scenario design, training as a multidisciplinary team, and use of video feedback can help maximise learning in these contexts. However the post-scenario debriefing has consistently been identified as the most important aspect of the learning experience [23].

Table 1.3.4 Operating theatre team NOTECHS assessment tool.

Leadership and management			
Leadership	Involves or reflects on suggestions; visible; accessible; inspires; motivates; coaches		
Maintenance of standards	Subscribes to standards; monitors compliance to standards; intervenes if deviation; deviates with team approval; demonstrates desire to achieve high standards		
Planning and preparation	Team participation in planning; plan is shared; understanding confirmed; projects; changes in consultation		
Workload management	Distributes tasks; monitors; reviews; tasks are prioritised; allots adequate time; responds to stress		
Authority and assertiveness	Advocates position; values team input; takes control; persistent; appropriate assertiveness		
Teamwork and cooperation			
Team building/maintaining	Relaxed; supportive; open; inclusive; polite; friendly; use of humour; does not compete		
Support of others	Helps others; offers assistance; gives feedback		
Understanding team needs	Listens to others; recognises ability of team; condition of others considered; gives personal feedback		
Conflict solving	Keeps calm in conflicts; suggests conflict solutions; concentrates on what is right		
Problem solving and decision making			
Definition and diagnosis	Uses all resources; analytical decision making; reviews factors with team		
Option generation	Suggests alternative options; asks for options; reviews outcomes; confirms options		
Risk assessment	Estimates risks; considers risk in terms of team capabilities; estimates patient outcome		
Outcome review	Reviews outcomes; reviews new options; objective, constructive, and timely reviews; makes time for review; seeks feedback from others; conducts post-treatment review		
Situation awareness			
Notice	Considers all team elements; asks for or shares information; aware of available of resources; encourages vigilance; checks and reports changes in team; requests reports; updates		
Understand	Knows capabilities; cross-checks above; shares mental models; speaks up when unsure; updates other team members; discusses team constraints		
Think ahead	Identifies future problems; discusses contingencies; anticipates requirements		
Below standard = 1	Basic standard = 2	Standard = 3	Excellent = 4
Behaviour directly compromises patient safety and effective teamwork	Behaviour in other conditions could directly compromise patient safety and effective teamwork	Behaviour maintains an effective level of patient safety and teamwork	Behaviour enhances patient safety and teamwork; a model for all other teams

NOTECHS, Nontechnical Skills.

A skilled facilitator can provide feedback, encourage learners to analyse specific behaviours and NTS, create a safe learning environment, and help learners to apply their knowledge to work-based settings [20].

Recognising the value of simulation and the fact that the majority of errors in surgery are the result of deficiencies in NTS, the SIMULATE programme has been developed in the United Kingdom [24]. It is a team-based simulation training programme in addition to workplace training. The programme provides training in both technical and NTS. Technical skills including TURP, TURBT, rigid and flexible URS, PCNL, laparoscopy, and robotics are taught using a combination of bench top and virtual reality simulators, whereas NTS are developed using an interactive human patient mannequin in a high-fidelity simulation environment. Trainees are provided with colleague support appropriate to the scenario (e.g. anaesthetist and nurse), and a video relay to the debriefing room allows full observation and feedback by an experienced faculty. The aim is to create an environment which is realistic enough for the surgical team to participate in the simulation and promote realistic team behaviours that can be discussed an analysed in debriefing sessions. NTS training has also been adopted by the Australasian College of Surgeons, the American College of Surgeons Association of Programme Directors in Surgery (ACS-APSD), and the Team Strategies and Tools to Enhance Performance and Patient Safety (team STEPS) [25, 26]. Further strengthening the argument to integrate such high-fidelity NTS training within urology curricula are the results of several well-designed studies by Lee et al. and Gettman et al. which have supported this type of NTS training in urology [27, 28].

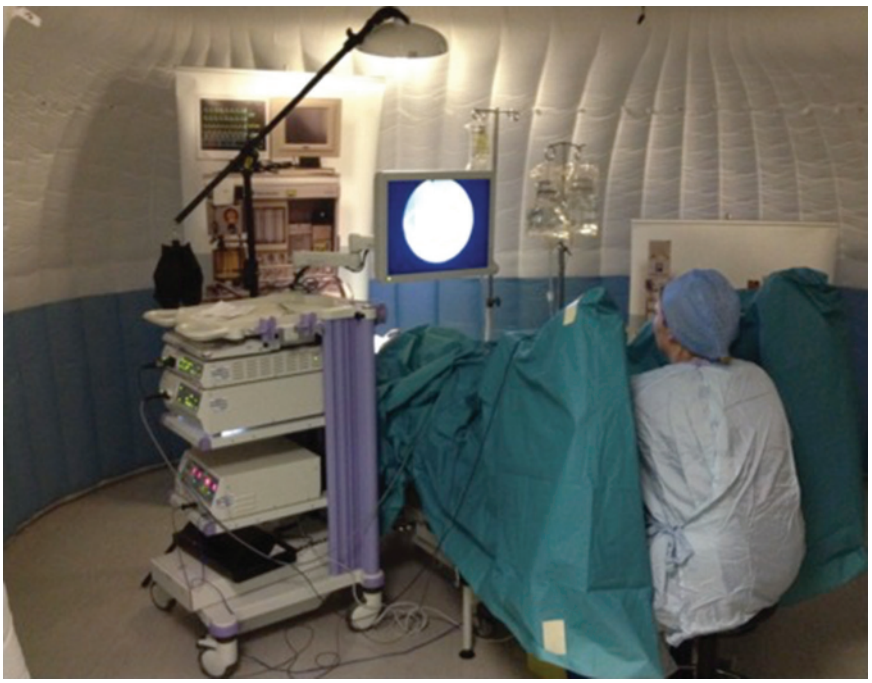

Figure 1.3.2 Image of simulated operating theatre.

1.3.9 Simulation Training Curriculums

A well-structured performance-based curriculum with well-defined end points and benchmark criteria remains the holy grail of simulation training. A number of barriers exist to developing such an ideal, namely cost, agreement on choice of simulator, and types of procedures requiring simulation training. Furthermore, integration of simulation programmes into training curriculum vary across different regions with each institution developing its own curriculum content and design. Much of the education literature supports the need to create a national standardised curriculum with proficiency-based strategies [29, 30]. It has been suggested that surgeons acquire technical skills through a series of steps, beginning with cognitive orientation, followed by repetition, and then demonstration of autonomy with that skill. A validated simulation programme can be used to support and implement such a proficiency-based curriculum because it has built-in objective measures of assessment from which proficiency levels can be derived [29]. The work by Aggarwal et al. has shown this through the design of a proficiency-based curriculum for basic laparoscopic skills acquisition [30]. Performance criteria were preset by pooling the scores of expert surgeons on the simulator. Thus benchmark proficiency criteria were defined for endpoints for each task such as time taken, number of errors, and path lengths. This created the basis of proficiency-based curriculum with clearly defined endpoints. Progression along the curriculum could be charted by passing set performance criteria so proficiency can be defined and competency ensured through end-of-module examinations. This curriculum has set the blueprint for ongoing research into the most effective simulation curriculum. Such performance-based simulated criteria has led to effective skills acquisition and improved operating theatre performance. For example, proficiency-based simulator training in laparoscopic suturing and knot tying improved performance in the operating room [31, 32]. Furthermore, a proficiency-based simulator curriculum ensures uniform skills acquisition by ensuring all trainees reach a set level of competency.

1.3.10 Assessment of Trainees

Before surgical simulation-based training methods can be used to assess the competency of surgeons, they must undergo initial testing across a variety of validity and reliability parameters (Table 1.3.5). This would include the assessment of face validity, which examines the realism of the simulator or simulated scenario; construct validity which differentiates novice from experienced operators; context validity examines whether the device can teach what it is supposed to teach; concurrent validity is the extent to which the results of the test correlate with the gold standard known to measure the same domain; and predictive validity is the extent to which an assessment will predict future performance [33]. Reliability relates to the reproducibility of an assessment and is linked to the assessment's validity. It allows educators to quantify the amount of random error in the

Table 1.3.5 Definitions of terms related to competence, training and assessment.

Face validity	Relates to realism of simulator. Does simulator represent what it is supposed to represent?
Concurrent validity	Degree to which simulator, as assessment tool, correlates with gold standard.
Construct validity	Refers to demonstrating difference in task performance based on experience level. Construct validity accounts for variance in test performance.
Content validity	Judgement of suitability of simulator as teaching modality involving formal evaluation by experts in subject matter of training device. This answers the question of whether a simulator can realistically teach what it is supposed to teach.
Predictive validity	Ability of test to predict future performance in operating theatre.

measured data, facilitating valid interpretations and the usage of trainee assessment scores. Correlation coefficients such as Cronbach's alpha coefficients are used to demonstrate internal consistency with reliability scores of at least 0.90 for high-stake assessments such as certification examinations [34].

As well as validity and reliability evidence, the application of simulation-based tools for assessment rely on establishing credible, defensible, and acceptable standards. Standards are categorised as either norm-based standards, which determine competency relative to the performance of a well-defined group (e.g. laparoscopic expert surgeons) or criterion-based standards, which determine competency based on a predetermined absolute level of performance. Criterion-based standards are preferred to assess competency because they imply a certain level of mastery of a skill [35].

1.3.11 Future of Simulation

One of the challenges for surgical educators is deciding which of the simulators to integrate into urological curriculums. With the rapid developments in technology, new simulators are constantly being developed, making research and validation of these tools challenging. Additionally more than one simulator exists for a given procedure, with a lack of comparative studies adding to the difficulties faced by programme directors. Often such decisions are based on results of research on older simulators, which have a better evidence base and on expert judgement. Compounding matters is that there are no universally accepted criteria on how to exactly validate a simulator, leading to methodological variations between studies, with a real need for a consensus regarding validation methodologies. Importantly the VR TURP trainer and the VR Uromentor (Symbionix) have been shown to improve surgical performance in the OR. Further studies with the aim of identifying this relationship are required. Although such studies are essential, they are intensive, time consuming, and pose numerous ethical conundrums. Showing this translation requires a large number of patients and training sessions and are therefore highly resource intensive. Ethical issues relate to patient consent. Patients want the best possible treatment and may withhold consent if participation entails a relative increase in their risk of complications. As such, these studies are best performed in well-organised, multicentre settings with approval from local ethics committees.

The ideal simulation programme would have a mix of high- and low-fidelity simulators to match various learning requirements. However, in reality, very few centres can afford the high-fidelity VR simulators. One suggestion has been to develop a hub-and-spoke service model where a larger, centralised simulation centre with better investments and a larger repertoire of simulators can liaise with peripheral centres to share resources [36].

Expert Opinion

The focus of healthcare education has now changed. Simulation in urology must not be used as a stand-alone tool for education but rather integrated into a comprehensive curriculum, in which knowledge can be attained alongside technical skills. Organising such a large-scale training programme requires directives from national organisations to ensure that a structured, standardised approach is used for urological training. This process has been initiated and will continue over the coming decades. Integration and dissemination at a local level requires committees of surgeons with special expertise to assess trainee competence. It is essential that competence be defined in accordance with proficiency levels. Emphasis must be placed on the importance of research in education to identify where trainees begin on the learning curve and how rapidly they plateau. The future of urology depends on novel training tools to match highly sophisticated operating techniques.

References

1 Ericsson, K.A. (2004). Deliberate practice and the acquisition and maintenance of expert performance in medicine and related domains. *Academic Medicine: Journal of the Association of American Medical Colleges* 79: S70–S81.

2 Das, S. (2007). Urology in ancient India. *Indian Journal of Urology* 23: 2–5.

3 Stark Ravings. The Link Trainer. http://www.starkravings.com/linktrainer/linktrainer.html. Accessed on 10 February 2014

4 Ker, J. and Bradley, P. (2007). Simulation in Medical Education. In: *Understanding Medical Education: Evidence, Theory, and Practice* (ed. T. Swanwick), 164–180. Chichester, UK: Association for the Study of Medical Education.

5 Ebersole S. A brief history of virtual reality and its social applications. http://www.academia.edu/629431/A_brief_history_of_virtual_reality_and_its_social_applications. Published 1997. Accessed 10 February 2014.

6 Seymour, N.E., Gallagher, A.G., Roman, S.A. et al. (2002). Virtual reality training improves operating room performance: results of a randomized, double-blinded study. *Annals of Surgery* 236: 458–463.

7 Scerbo, B. (2005). Medical virtual reality simulators: have we missed an opportunity? *Human Factors and Ergonomics Society Bulletin* 48: 1–3.

8 Abboudi, H., Khan, M.S., Abourmarzouk, O. et al. (2013). Current status of validation for robotic surgery simulators – a systematic review. *BJU International* 111: 194–205.

9 Rogers, S.O. Jr., Gawande, A.A., Kwaan, M. et al. (2006). Analysis of surgical errors in closed malpractice claims at 4 liability insurers. *Surgery* 140: 25–33.

10 Ahmed, K., Jawad, M., Dasgupta, P. et al. (2010). Assessment and maintenance of competence in urology. *Nature Reviews Urology* 7: 403–413.

11 Wilhelm, D.M., Ogan, K., Roehrborn, C.G. et al. (2002). Assessment of basic endoscopic performance using a virtual reality simulator. *Journal of the American College of Surgeons* 195: 675–681.

12 Matsumoto, E.D., Hamstra, S.J., Radomski, S.B., and Cusimano, M.D. (2002). The effect of bench model fidelity on endourological skills: a randomized controlled study. *The Journal of Urology* 167: 1243–1247.

13 Watterson, J.D., Beiko, D.T., Kuan, J.K., and Denstedt, J.D. (2002). Randomized prospective blinded study validating acquistion of ureteroscopy skills using computer based virtual reality endourological simulator. *The Journal of Urology* 168: 1928–1932.

14 Schout, B.M., Hendrikx, A.J., Scherpbier, A.J., and Bemelmans, B.L. (2008). Update on training models in endourology: a qualitative systematic review of the literature between January 1980 and April 2008. *European Urology* 54: 1247–1261.

15 Wijn, R.P., Persoon, M.C., Schout, B.M.A. et al. (2010). Virtual reality laparoscopic nephrectomy simulator is lacking in construct validity. *Journal of Endourology* 24: 117–122.

16 Brewin, J., Nedas T, Challacombe B, et al. Face, content and construct validation of the first virtual reality laparoscopic nephrectomy simulator. *BJU International* 106, 850–4 (2010).

17 Tjiam, I.M., Persoon, M.C., Hendrikx, A.J. et al. (2012). Program for laparoscopic urologic skills: a newly developed and validated educational program. *Urology* 79: 815–820.

18 Brinkman, W.M., Tijam, I.M., Schout, B.M. et al. (2013). Results of the European asic Laparoscopic Urological Skills examination. *European Urology* 65: 490–496.

19 Feifer, A., Al-Ammari, A., Kova, E. et al. (2011). Randomized controlled trial of virtual reality and hybrid simulation for robotic surgical training. *BJU International* 108: 1652–1656.

20 Brewin, J., Ahmed, K., and Challacombe, B. (2014). An update and review of simulation in urological training. *International Journal of Surgery* 12: 103–108.

21 Sevdalis, N., Davis, R., Koutantji, M. et al. (2008). Reliability of a revised NOTECHS scale for use in surgical teams. *American Journal of Surgery* 196: 184–190.

22 Yule, S., Flin, R., Maran, N. et al. (2008). Surgeons' non-technical skills in the operating room: reliability testing of the NOTSS behavior rating system. *World Journal of Surgery* 32: 548–556.

23 McGaghie, W.C., Issenberg, S.B., Petrusa, E.R., and Scalese, R.J. (2010). A critical review of simulation-based medical education research: 2003–2009. *Medical Education* 44: 50–63.

24 Shamim Khan, M., Ahmed K, Gavazzi A, et al. Development and implementation of centralized simulation training: evaluation of feasibility, acceptability and construct validity. *BJU International* 111, 518–23 (2013).

25 Hull, L., Arora, S., Aggarwal, R. et al. (2012). The impact of nontechnical skills on technical performance in surgery: a systematic review. *Journal of the American College of Surgeons* 214: 214–230.

26 Dickinson, I., Watters, D., Graham, I. et al. (2009). Guide to the assessment of competence and performance in practising surgeons. *ANZ Journal of Surgery* 79: 198–204.

27 Lee, J.Y., Mucksavage, P., Canales, C. et al. (2012). High fidelity simulation based team training in urology: a

preliminary interdisciplinary study of technical and nontechnical skills in laparoscopic complications management. *The Journal of Urology* 187: 1385–1391.

28 Gettman, M.T., Pereira, C.W., Kipsky, K. et al. (2009). Use of high fidelity operating room simulation to assess and teach communication, teamwork and laparoscopic skills: initial experience. *The Journal of Urology* 181: 1289–1296.

29 McClusky, D.A. 3rd and Smith, C.D. (2008). Design and development of a surgical skills simulation curriculum. *World Journal of Surgery* 32: 171–181.

30 Aggarwal, R., Grantcharov, T.P., Eriksen, J.R. et al. (2006). An evidence-based virtual reality training program for novice laparoscopic surgeons. *Annals of Surgery* 244: 310–314.

31 Stefanidis, D., Acker, C., and Heniford, B.T. (2008). Proficiency-based laparoscopic simulator training leads to improved operating room skill that is resistant to decay. *Surgical Innovation* 15: 69–73.

32 Korndorffer, J.R. Jr., Dunne, J.B., Sierra, R. et al. (2005). Simulator training for laparoscopic suturing using performance goals translates to the operating room. *Journal of the American College of Surgeons* 201: 23–29.

33 Ahmed, K., Miskovic, D., Darzi, A. et al. (2011). Observational tools for assessment of procedural skills: a systematic review. *American Journal of Surgery* 202: 469–480 e6.

34 Downing, S.M. (2004). Reliability: on the reproducibility of assessment data. *Medical Education* 38: 1006–1012.

35 Yudkowsky, R., Downing, S.M., and Tekian, A. (2009). Standard setting. In: *Assessment in health professions education* (ed. S.M. Downing and R. Yudkowsky), 119–148. New York: Routledge.

36 Ahmed, K., Amer, T., Challacombe, B. et al. (2011). How to develop a simulation programme in urology. *BJU International* 108: 1698–1702.