Practical Simulation in Urology

Chandra Shekhar Biyani
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Editors

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Foreword

Since the beginning of this century, traditional surgical training has changed completely. Not only has the "see one—do one—teach one" paradigm been completely abandoned, but there are also new theories and models to improve surgical training, which have been introduced.

Our daily surgical practice has been revolutionized, not just in terms of open surgery, but also with the introduction of minimally invasive surgical techniques, such as laparoscopy and endourology.

Simulation in surgical training has been developed through several models of simulation. This started with low-fidelity simulators (i.e., training boxes for laparoscopy) and has now reached future dimensions of virtual reality and even artificial intelligence with deep-learning. This is further supported by new theories of learning, such as proficiency-based training, defined validation, and the introduction of novel training models, thus opening the new field of surgical science.

There is no doubt that the next generation of surgeons will be much better prepared for new and, of course, also well-established techniques.

This book represents an important step in this direction. The editors were able to gather information from all relevant groups working in this field of simulation and surgical training, including members of the British Association of Urological Surgeons (BAUS) and most relevant sections of the European Association of Urology (EAU), such as the EAU Section of Uro-Technology (ESUT), the EAU Robotic Urology Section (ERUS), and the EAU Section of Urolithiasis (EULIS) as well as the Training Research Group of the European School of Urology. They have to be congratulated for their effort.

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Foreword

There is an increasing concern that current UK trainees at the end of their training are less experienced than their previous counterparts and continue to require more education, skills, and support when they take up their consultant posts in the form of mentoring.

It is generally accepted that the number of hours required to become an "expert" is 10,000–30,000 but currently in the UK, our trainees experience only half that time in training. Skills Training and Simulation have, therefore, been seen as one of the mechanisms to resolve the situation, encompassing both the acquisition of technical and non-technical skills in a safe environment. This book provides a detailed overview of the latest simulation models that have been assessed in relation to a range of urological procedures.

There is no evidence-based universal model for teaching, but this book features a comprehensive critical analysis of the latest simulation techniques to allow trainers and trainees to look at incorporating simulation into the curriculum. In addition, it also addresses low-cost simulation models and the implementation process for simulation-based program.

The ultimate test of simulation is "whether the model and content are able to reduce surgical errors, improve patient safety, and reduce operating time and costs," and the authors are to be congratulated on a book that goes a long way toward addressing these issues.

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President of the Endourological Society
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Preface

Simulation training offers learners an extremely valuable opportunity to receive real-life scenario training. Much of the advancement in simulation training over the past century was accomplished in the aviation industry with flight simulation. Armed with a mission to reduce costs and provide better training, flight simulators have been leading the way in aeronautical innovation. Can we say the same for Healthcare Simulation? Over the past two decades, simulation training in healthcare has grown exponentially, in large part due to improvements in technology. Simulation in healthcare has expanded into all disciplines. However, there is a long way to go before we catch up with the aviation industry.

Urology programs are incorporating simulation into their curriculum. Thoughtful planning is critical in executing a successful simulation exercise and experience. This is the first specialty-specific simulation book to improve understanding of factors shaping a safe and efficient learning experience and justifies the sentiments expressed by Dr Mayo "*There is no excuse today for the surgeon to learn on the patient*" [1].

The quality of urology training that we deliver dictates the quality of urological care both now and in the future. There is one thing that we all see very commonly with regard to simulation training, which is that, deep down, we all know what it is that we need to do for trainees. We know exactly what we should be doing to help trainees, but despite knowing all of that, we just can't find a way to act on it. As McGaghie et al stated, "*Simulation-based education is not easy or intuitive, and clinical experience alone is not a proxy for simulation instructor effectiveness*" [2]. When considering the feasibility of incorporating simulator-based training into a urology educational curriculum, it is important to choose the right simulator. The fidelity of a simulator should match the complexity of the task or procedure to be trained and/or assessed. It is widely recognized that non-technical skills can also be effectively taught through simulation. However, there is no formal support structure for trainers to develop their teaching skills in non-technical skills in the majority of programs. Another challenge trainers face is how to implement a simulation-based program. As compared to surgery in real-life, simulation training is never real and perfect, but that should not stop our quest for perfection. When we decided to write

Practical Simulation in Urology, it was with several observations and beliefs that were based on our combined experience of teaching and training various surgical and urological skills.

Against this background, this book is designed to present a state-of-the-art perspective on the Simulation in Urology, contributed by well-recognized educators and experts with a sub-specialty interest in urology. Trainers frequently face dilemmas such as: what are my responsibilities as a trainer? what methods to use for training? how to assess and implement training? These basic needs are reflected in our compilation of this book, which has various chapters covering the core requirements of a trainer. In addition, a concise summary at the beginning of each chapter followed by key points at the end of each chapter helps to reinforce the message. We sincerely feel that we have achieved the correct balance in terms of content, and we have not introduced errors of fact or judgment. It is our hope that the *Practical Simulation in Urology* book will mature into the standard reference text in the field of urology simulation. We feel this collection will prove to be a valuable resource for both trainers and researchers in simulation. Future editions will keep pace with the rapidly changing landscape of healthcare simulation. Personally, it has been a true privilege to be able to edit this textbook.

We are grateful to our authors for attempting to write their chapters during the COVID-19 pandemic while maintaining a consistent style, as well as for their cooperation in allowing us to change chapters to minimize topic overlap. We would like to thank all the trainees and trainers who have provided knowledge related to urological simulation over the years. We are most grateful to our families for all the support during the compilation of this book. Finally, it is our pleasure to thank the publisher for their guidance, cooperation, suggestions, and views on the layout of the book.

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Chapter 1
The Use of Simulation in the History of Urology

Jonathan Charles Goddard

1.1 Introduction

In this world of digital technology, high-definition video and virtual reality, surgical simulation may appear to be a very modern concept. However, if you trouble to ask yourself, "What is surgical simulation?" and realize that, at its most basic, it is anything which allows one to practice and then teach a surgical technique away from the actual patient, it is easy to see that this concept is almost as old as the surgery itself.

Perhaps the earliest evidence we have of surgical simulation comes from the ancient Hindu surgeons. Surgical techniques were demonstrated and practiced on vegetables such as cucumbers and gourds (both helpfully providing a realistically firm skin and soft interior). Suturing could be perfected on cloth or soft leather. From a urological aspect, catheterization was practiced on an unbaked earthen vessel containing water, one assumes with a suitable urethral spout. The unfired soft clay would reveal any rough manipulation and perhaps end in a leak of the water if the student was unduly forceful. Drainage of any fluid filled cavities, for example, a hydrocele or scrotal abscess, was practiced on a leather bag filled with soft mud or water [1].

Urology has always been at the forefront of technological advances and has seen many *sea changes* in practice, often dependent on the introduction of new instruments. Historically, urology has been granted the position of the first surgical specialty. This is due to the ancient operation of perineal lithotomy; the open removal of bladder stones. This is evidenced in the Hippocratic Oath which contains the phrase, "I will not cut for the stone, but leave that to specialists of that craft" [2], that

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is, stonecutters or ancient urologists. Stonecutting was often a family business, the skills and secrets of the craft being passed down from one generation to the next. Although there is no evidence of simulation being used as a teaching aid in these families, this was certainly seen when a new style of lithotomy appeared in the eighteenth century.

1.2 With the Help of the Dead

One way of practicing an operation without harming a living patient is to use a dead one. The study of human anatomy by dissection was carried out in ancient India and Greece, but fell out of favor until the Renaissance. By the eighteenth century, the demand for cadavers by anatomy schools was such that fresh corpses were stolen to order from graves by resurrection men or body snatchers. Their dissections formed part of the surgeons' practical training, improving their knife skills and preparing them for the operations they were to carry out, as well as teaching them anatomy. Corpses were also used for practice in specific procedures.

In the early part of the eighteenth century, William Cheselden (1688–1752), a well-known London Surgeon, traveled to Amsterdam to watch the Dutch anatomist and surgeon, Johannes Jacobus Rau (1668–1719) carry out a new operation for bladder stones. This novel procedure had been introduced in France by a traveling lithotomist called Jacques de Beaulieu (1651–1714), also known as Frère Jacques. The technique involved cutting through the perineum into the bladder more laterally than was usual. For this to be successful, the incision had to be precise, avoiding the rectum and lateral vessels; Frère Jacques' results were sadly variable, to say the least. Following a run of very poor results, he fled to Amsterdam, where his idea was seen and copied by Rau. Unfortunately, Rau was not inclined to share the technique and when Cheselden visited him, he shielded the operative field with his hand, hiding his incision.

Cheselden, having a good idea of what the new approach involved, returned to London and practiced on cadavers until he was happy with his new skill. This simulation model worked; with only six deaths in his first 100 patients, Cheselden's fastest time, from knife to skin to stone extraction, was said to be 54 s. In comparison, of Frère Jacques 60 French patients, 13 were cured but 25 died and the remaining 22 were left crippled [3].

At around the same time, John Douglas (c.1690–1743), a contemporary of Cheselden, introduced a completely different approach to the bladder, suprapubic. This was a bold operation at a time when, with no anesthesia or muscle relaxation, the inadvertent opening of the peritoneum would result in irreplaceable release of the bowels and the lack of antibiotics would, almost certainly, lead to death by peritonitis. Understandably, Douglas practiced his operation on cadavers many times before trying it out on a living patient. He had also researched the procedure fully. He found a reference to the idea in a 1590 book on the cesarean section by Frances Rosset (c.1535–c.1590) of Montpelier. Rosset had also carried out the simulation on dead bodies. Douglas though, was the first to move from simulation to live practice [4]. John Douglas was made a Freeman of both the City of London and the Company of Barber–Surgeons and was also appointed as lithotomist to the Westminster Hospital [5]. However, within a short time, his new and revolutionary technique fell out of favor, not to re-emerge for over a century. This was probably due to surgeons inadvertently opening the peritoneum, as mentioned above. It is unlikely that many surgeons practiced the new technique on cadavers prior to trying it on patients. Although, clearly an excellent surgical idea, it was hampered by pre-dating anesthesia, but also it was perhaps too radical a change for surgeons unprepared by suitable training.

1.3 Simulation in the Earliest Minimally Invasive Surgery

Although lithotomy gave urology its prime place in specialist surgery, it remained one of the "Capital Operations"; meaning, quite frankly, along with amputation and trephining, it was highly likely to be fatal. Therefore, it was a long-sought goal of surgeons to access the bladder and remove stones via the natural orifice of the urethra, without cutting. This, the first minimally invasive surgery, was finally achieved in the early part of the nineteenth century, in Paris.

The operation of passing an instrument down the urethra to destroy bladder stones was called lithotrity; the instrument was a lithotrite. The first working lithotrite was introduced by Jean Civiale (1792–1867) who demonstrated his instrument on a patient on 13th January 1824, at the Necker Hospital in Paris in front of the commissioners of the Academie de Medecine. The technique was to grasp the stone and drill several holes in it rendering it fragile enough to break up; it took both skill and time to manipulate the stone. Civiale, however, used an unusual simulation technique to increase his manual dexterity with the lithotrite. He was said to have walked the streets of Paris with a lithotrite in his right hand, using it to pick nuts out from his tailcoat pocket [6]. Lithotrity was carried out blindly and completely by feel and was not mastered by all surgeons, but it was an important technological advance for urology and the new French operation soon became well known.

William Jeaffreson (1790–1865) was a surgeon in Suffolk where bladder stones were particularly common, probably due to dietary reasons. In 1833, he diagnosed a stone in one of his friends and although he was skilled in perineal (open) lithotomy, he decided to take him to London to consult Mr. William Birmingham Costello (1800–1867), who was using the new French lithotrite. Jeaffreson watched Costello operate on his patient and friend and inspired, went off to Millikan's, the instrument maker in the Strand, to have his own lithotrite made. He returned to Suffolk but did not immediately operate on patients. Jeaffreson practiced lithotrity first on a dead body. Still not satisfied, he made what he termed "a rough machine" as best he could to "resemble a human bladder." Jeaffreson gives no more details about this early simulation model and sadly no picture in his 1834 report in the Lancet [7]. However, once satisfied with his self-training, on 7th May 1834, he passed his lithotrite into a

64-year-old William Kent, a laborer with a debilitating bladder stone. Training on his simulator was time well spent; it required 37 sittings to slowly chip away at the stone and the man usually walked the three miles each way to visit Jeaffreson's surgery [7]; a testament, I would say, to his gentle, well practiced, dexterity.

In his 1845 book, *De la litheretie ou extraction des concretions urinaires*, Joseph Emile Cornay (fl. 1850), of Rochfort, France, described an artificial rubber bladder model for practicing lithotrity [8]. It could be rolled up for storage and transport in a metal tube [9]. Unlike Jeaffreson's one-off, homemade model, surgeons could now purchase a simulator to train and hone their skills in the new technique. One wonders how many eager surgeons did this and how many had their first experience of a lithotrite inside the urethra of a patient; no doubt his first experience of it too.

1.4 A Clearer View

The next great step in urology (and indeed in medicine in general) was the ability to see the inside of the urinary system. Early attempts involved reflecting light down a narrow speculum, initially, using the flame of a candle. One of the earliest, reasonably practical, endoscopes was made in 1853 by Antonin J. Desormeaux (1815–1894) of France [10]. Desormeaux used for his light source an oil lamp lit with a mix of alcohol and turpentine, called gasogene. It gave a bright light and enabled Desormeaux to diagnose diseases of the urethra and treat them winning him the title of "The Father of Endoscopy" [11].

At some point, a Desormeaux endoscope, or one very similar, was acquired by Francis Cruise (1834–1912) a Dublin surgeon. Cruise was disappointed with its poor illumination and soon abandoned it. However, he later returned to the idea of endoscopy and planned to improve on Desormeaux's design. Cruise increased its light intensity by the use of dissolved camphor and petroleum in his lamp instead of gasogene; this light source also transmitted color more accurately [12]. He added a protective outer mahogany casing to decrease the risks of burns to its user and subjects, and a new window and mirror system to the tip of the instrument. This early lens apparatus was divided into an adjustable reflector system along with the Desormeaux inspired concave lens to focus the light. On 4th April 1865, his friend and colleague (and former teacher) Dr. Robert McDonnell (1828–1889) set Cruise a little test. Into the bladder of a fresh cadaver (via a suprapubic incision) he placed three objects. Cruise correctly identified a brass screw, a bullet, and a piece of plaster of Paris with his new endoscope, thus passing his friend's simulator test [12]. Cruise may well have already practiced with his new instrument on cadavers, but here we see simulation being used as an assessment.

Although cadaveric models gave a realistic experience of live surgery, there were, of course, a limited number of easily available subjects. The invention of a practical cystoscope in the 1880s led to a revolution in diagnosis and, therefore, better training was needed. The original cystoscope makers, Max Nitze (1848–1906) and Josef Leiter (1830–1892) also sold bladder simulators, were then called

Fig. 1.1 Nitze Bladder Phantom. From the Product Catalog of Mueller & Co., Chicago, 1911. Image in the public domain

phantoms. The 1887 sales catalog of J. Leiter and Co., contained a phantom designed by Leopold van Dittel (1815–1898) the famous Austrian Urologist who had worked with Leiter on his early cystoscopes. The phantom consisted of a tin sphere with vessels painted on the inside and to which tiny bladder tumors could be attached for the practicing surgeon to spot [9]. Max Nitze's rubber phantom also had artificial ureters to allow surgeons to practice ureteric catheterization (Fig. 1.1).

Edwin Hurry Fenwick (1864–1944) of the London Hospital was a keen advocate of the new cystoscope and was key in its introduction into Great Britain. He advised the use of the phantom even prior to practice on the cadaver. Phantoms, he said, were often available for a short-term loan from the instrument makers, who, of course, were keen to sell their new cystoscopes. He described the Leiter phantom as having blood red irregular masses on the walls, calculi and foreign bodies at the

Fig. 1.2 Heywalt Bladder Phantom by C. G. Heynemann of Leipzig, c.1930s. Note the open top and mirror to monitor the student's movements. Image reproduced from the EAU European Museum of Urology with kind permission of the EAU History Office

base, with the position of the ureters and urethra marked. A window on the top allowed an external view, to check where the scope was pointing, if the user became disorientated, as he said, "The eye can thus guide and teach the hand" [11] (Fig. 1.2).

Multiple bladder models were designed by surgeons and produced by instrument makers, presumably at some expense. However, in 1908, Richard Knorr (1866–1928), the Berlin gynecologist, suggested simply practicing with the cystoscope in a bowl of water, identifying homemade tumor models made of wax [13].

1.5 Models for Endoscopic Surgery

Endoscopic surgery followed close on the heels of diagnostic endoscopic examination. Early on, small bladder tumors were snared and then, following the work of Edwin Beer (1876–1938) [14], fulgurated. In 1926, the first transurethral resection of the prostate (TURP) was performed [15] and this new, seemingly minimally invasive treatment, took off at apace, especially in the USA. Unfortunately, the apparent simplicity of TURP led to a multitude of complications and deaths as surgeons failed to grasp the underlying complexity of the new operation. The two major textbooks on the technique during the early era of TURP were by Roger Barnes (1897–1982), of Los Angeles, and Reed Nesbit (1898–1979), of Michigan, and were both published in 1943 [16, 17]. Both authors agreed that the would-be resectionist train with the resectoscope away from the live patient prior to their first TURP. Barnes suggested using an ox heart model, passing the scope through the valves to practice resection of the muscular ventricular walls. Nesbit encouraged the resection of meat underwater. George Otto Baumrucker (1905–1991), who wrote an excellent little book on the hazards of TURP, also suggested resecting meat in a bowl of water to allow the surgeon to familiarize himself or herself with the diathermy cutting and coagulating method. He further suggested that the trainee practice TURP on a homemade model constructed from the rubber ball of a large gastric syringe, cut in half, containing a "prostate" made of children's modeling clay [18]. Barnes explained that the technical skill to manipulate this unfamiliar and complex surgical instrument meant that the number of procedures required to become competent in TURP was much greater than with open surgery. He suggested 100 TURPs were required to gain proficiency whereas after assisting in four or five open prostatectomies a surgeon could do one alone [16].

At around the same time an alternative to the TURP and resectoscope arose, the punch. The prostatic punch is an unfamiliar instrument to the modern endourologist accustomed to the fine optics, digital vision, and efficient diathermy of the latest resectoscopes. The punch was a direct vision instrument, there was no lens system; it was perhaps more akin to looking through the window of a rigid sigmoidoscope down the column of fluid flowing into the bladder. The prostate was inspected and the side window of the punch opened. The obstructing tissue fell into this window and the blade was advanced to chop it off. Bleeding points were controlled with a Bugbee type electrode. The prostatic punch required skill to master but could be successful in the right hands.

Thomas Lightbody Chapman (1903–1966) who founded the urological department at the Victoria Infirmary, Glasgow, traveled to the Mayo Clinic in America to learn the new technique of punch prostatectomy. Chapman began carrying out punch prostatectomies in Glasgow from January 1938 [19]. Chapman was a great teacher who used innovative techniques to educate his students in the skills of punch prostatectomy. These included a cine-film using both live-action and animation to demonstrate the technique and a training model where the trainee surgeon could be observed punching out a phantom prostate. In order to train his registrars and to ensure they had grasped the necessary skills of the punch before allowing them to operate on patients, he invented this teaching aid. The phantom was made of rubber with a Perspex plate on the bladder side so Chapman could watch how a trainee punched away at a (replaceable) prostate made of a plastic-like substance called Vinamould. The learning curve took several weeks [20]. Chapman also published a description of his teaching model so others could use it [21] (Fig. 1.3).

The introduction of the Hopkins Rod lens and Karl Storz cold light source revolutionized endoscopy and endoscopic surgery in the 1970s. The much-improved vision heralded a rise in the popularity of TURP. The instrument catalogs of the Karl Storz Company around this time included a TURP practice model. An apple was

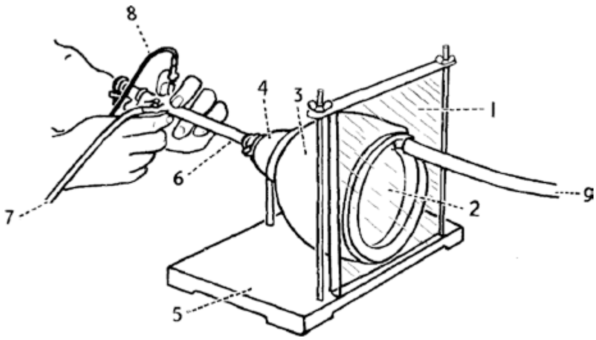

Fig. 1.3 Diagram of Chapman's Punch Phantom. Reproduced from his paper with kind permission of BJUI

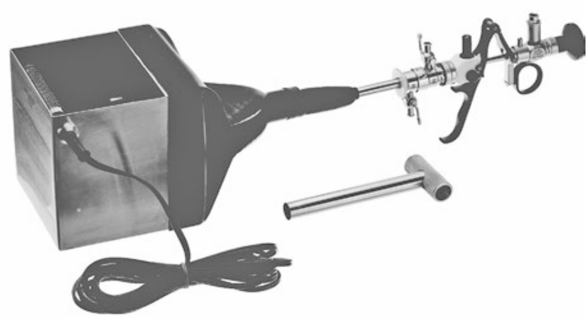

Fig. 1.4 Storz TURP Trainer. © KARL STORZ SE & Co. KG, Germany. Reproduced with kind permission

used as the surrogate prostate [22]. The surgeons no longer had to make their own out of rubber syringes and modeling clay (Fig. 1.4). TURP, which can be a tricky operation to master, remains a key procedure to assess overall competency for urology trainees.

1.6 Urological Laparoscopy: A Step Beyond the Gallbladder

Laparoscopy was led by the gynecologists, the general surgeons followed, realizing its utility for cholecystectomy. In urology, the first laparoscopic nephrectomy was carried out by Ralph Clayman (contemporary) in the USA. Clayman's technique was observed by two British urologists, Malcolm Coptcoat (1955–1999) and Adrian Joyce (contemporary) who realized that this was a technique they could quickly introduce into the UK. With the help of John Wickham (1929–2017), they did. Wickham was a great advocate of minimally invasive surgery and was also keen to teach. Removal of the kidney, however, was technically more challenging than laparoscopic sterilization or even cholecystectomy and the learning curve was hard and long; too long to introduce sensible training programs based on the traditional apprenticeship style of surgical learning. A more structured, stepped, means of learning was needed. Like the lithotrite of old, laparoscopy introduced a completely new style of operative surgery. The alien movements of the new instruments had to be first learned on simulators in “dry labs,” then on animal models in “wet labs” to allow the trainees to ascent the learning curve before being mentored through the surgery on patients. The long instruments were “fixed” at the point of entry through the abdominal wall creating a pivot point at some distance from the operative field. This novel movement can be practiced on a basic trainer, which is essentially a box with holes in it. Occasionally a simple cardboard box and borrowed instruments appeared in doctors’ offices and registrar’s rooms for informal practice. Manufactured laparoscopic trainers soon followed (Fig. 1.5).

Fig. 1.5 The typical “Lap. Trainer” in the trainee’s rest room. Set up and ready for impromptu practice. Author’s image: very contemporary!

1.7 The Robot

The first robotically assisted radical prostatectomy was carried out in 2000 [23]. The robot translates the movements of the surgeon's hands to the instruments within the body cavity. Increased degrees of movement make robot-assisted surgery more akin to open surgery than to laparoscopic. Movement is more natural, but tactile sensation, particularly that of tissue tension, is lost. So once again, a new style of surgery had to be learned. The robot heralded a new era in urology. From the pioneering cystoscopes of the nineteenth century to laparoscopic surgery, the focus on improving urological technology had been in optics, the robot now brought us truly into the digital world. The robot is to some extent, its own trainer. Movements of its powerful arms, but delicate instruments, could initially be easily practiced on inanimate objects. Counters were moved, washers or sweets were stacked, and knots were tied, all well away from the patient. The digital nature of the robots now allows a video-game style of training; the initial technical skills can now be acquired not merely away from the patient, but away from the real world, in the virtual universe.

1.8 Conclusion

Practice makes perfect and practice away from the living patient, although not able to reproduce the exact experience, has long been used to advance along that path. All surgical skills can be enhanced by practice *ex vivo*, whether knot tying on a door handle or cutting out a bladder stone from a cadaver, but in the history of urology, it is the great *sea-changes* in techniques which have benefitted from surgical simulation most. The move from open lithotomy to blind lithotrity literally required the surgeon to adapt to the loss of vision and enhance his tactile skills. The passage of sounds, bougies, and stiff metal catheters into the bladder was skill surgeons, as a group, were expected to already possess, but the fine manipulations of the new lithotrites within the bladder, unseen, was completely new. Sadly, not many surgeons would have had the foresight of William Jeaffreson to create a practice model or have access to a manufactured phantom. The leap to visualization of the inside of the bladder by cystoscopy was another novel and difficult skill to master. Indeed, the ability to use the cystoscope defined and created the new specialty of urology at the beginning of the twentieth century. The early optics inverted the image and with the poor light sources available, even simple orientation would be challenging. It is unsurprising that the instrument catalogs of the time displayed bladder phantoms alongside the new cystoscopes. It was the laparoscope, however, which necessitated the modern era of surgical simulation. Although superficially similar to endoscopic surgery, the wildly alien upper arm movements required of the surgeon due to the fulcrums of the long rigid instruments, required significant new learning and adaptation by the urologists at the time. The laparoscopic simulators and teaching courses, which were soon required, led to a realization that surgical simulation should be an integral part of urological and indeed surgical training.

What is fascinating, looking back at the surgical simulation of all types throughout the history of urology, are the simple yet innovative solutions urologists, over time, have applied to improve their skills prior to approaching the patient. Virtual reality, 3D visualization, and gaming concepts I am sure will be the way forward (and safer surgeons I hope will be made) but the huge technical strides taken in surgical urology have been on the stepping-stones of ox hearts, apples, bowls of water, and cardboard boxes.

Key Points

- Surgical simulation is not a modern concept.
- Urology has historically been associated with new technologies.
- All throughout the history of urology simulation has sat side by side with these new surgical innovations.
- Some simulators were very simple and cost effective and yet still practical and useful.
- In ancient India, a clay pot model was used to practice catheterization.
- Often, operations were practiced first on cadavers.
- New techniques and instruments such as the lithotrite required quite new skills, so simulations were used.
- Phantom bladders were invented alongside the new cystoscopes to enable surgeons to train.
- One of the greatest changes in technique was laparoscopy and this led directly to the modern concept of surgical skills training.

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Chapter 2
Surgical Education and Learning Theory

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2.1 Introduction

The current surgical training model was introduced in 1889 by William Halsted at the Johns Hopkins Hospital, in the USA. The initial model implemented the German-style residency training system with an emphasis on graded responsibilities [1, 2]. This training was completed in the hospital wards and in the operating room under the supervision of a graduate surgeon. In the twenty-first century and on objective evaluation using the Halstedian approach to training, it is clear that the method is time-consuming and increases the risk to patients [3].

Advances in educational theory, in addition to mounting pressures in the clinical environment due to the advent of minimally invasive surgery in the 1980s, have advocated a change in this traditional approach to the teaching and acquisition of new surgical skills, both technical and non-technical, to overcome new technical challenges.

The learning of surgical techniques includes the acquisition of several psychomotor skills, defined as mental and motor activities required to perform a given manual task [4].

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It became clear that the training model proposed by Halsted "see one, do one, teach one" would have to be replaced by a model that prioritized the simulation with many repetitions and always under qualified supervision [5]. To facilitate the training of the new skills, simulators and simulation environments were developed, thus reducing the risks to patients, and offering the learners a safe learning space to develop their skills outside the operating room.

Surgical education and training has changed over the past three decades and has brought a new set of challenges to academic surgeons. The changing nature of the health care delivery system, the increased complexity of patients and devices, advances in technology, the integration of continuous quality improvement into daily medical practice, and increasing demands on surgical faculty have all impacted the preparation of surgical residents for practice [6].

2.2 Educational Theories of Learning

The understanding of learning educational theories by preceptors of surgical programs and undergraduate teachers can facilitate the structuring and application of training models in procedures and operative techniques [7].

2.2.1 Practical Skills Learning

The method "see one, do one, teach one" can be applied to general practical skills learning and teaching. However, it creates stress for the learner, and after an early complication, it may inhibit further application of a particular skill [8].

Miller [9] has proposed a hierarchical sequence of competence. He further proposed four levels, based on (1) "knowing," followed by (2) "knowing how," (3) "demonstrating how," before reaching the final stage of (4) "doing." Thus, in each progressive step toward competence, the trainee advances through the necessary cognitive and behavioral steps that underlie the next step, building the knowledge that eventually assists and supports the execution of a specific skill. There is an inherent flaw in this theoretical proposition as it is "assumed" that the trainee has successfully developed competence from the previous stages including knowledge.

2.2.2 Motor Skills Acquisition

It seems logical that successful completion of a practical procedure is based on successful acquisition and execution of psychomotor skills.

Fitts and Posner [10] have established a theory for the acquisition of motor skills in three phases: the cognitive phase (when the skill is learned), the associative phase (when performance is becoming skilled), and the autonomous phase (when the skill has become fully automatic and can be performed without thinking much about the task) [11].

At the cognitive stage, the learner intellectualizes the task. The trainee is a novice and receives nearly all new information in the form of declarative knowledge [12]. Declarative knowledge is a knowledge of facts [13] and is used to handle novel events and acquire new information. It must be processed through working memory to execute a task. In essence, the trainee needs to consciously think about every step of the procedure. This phase is typified by trial and error and retrieval of knowledge from long-term memory is slow and effortful [14].

With continuous practice and relevant feedback, the trainee reaches the associative or integrative stage, during which knowledge is translated into appropriate motor behavior. Errors in the initial execution of the skill begin to be eliminated and connections among the various steps of the procedure are strengthened [10]. After increased opportunities for performing related tasks, the trainee becomes more able to generate improved performances with less effort. Finally, continuous practice with trainer encouragement and successful negotiation of earlier stages results in a more qualified performance in the autonomy phase, in which the trainee does not think about how he/she is performing and begins to focus on the other aspects related to optimal task performance. During this phase declarative knowledge transitions into procedural knowledge and becomes what is called "automated." Procedural knowledge is about the execution of actions and it is utilized outside of our conscious awareness or control, and therefore is effortless [15]. The reason for this is that as skills become automated, we no longer have to consciously process the relevant information and the procedural knowledge through working memory. These newly nonconscious mental processes free up working memory space to deal with novel and unanticipated intraoperative events [16].

Expert performance represents the highest level of technical skill acquisition. Through extended experience, it is the result of a gradual improvement in performance [17, 18]. According to Ericsson [17, 18], most professionals reach a stable, average level of performance and maintain this status quo for the rest of their careers. Surgical experts, consequently, have been defined as experienced surgeons with repeatedly better results than non-experts. Many professionals probably do not attain true expertise in practical skill acquisition. It seems logical to state that regular practice is an important determinant of performance [19].

However, it is apparent that volume alone does not account for the skill level among surgeons. Ericsson [17] has also argued that the number of hours spent in deliberate practice, rather than just hours spent in surgery, is an important determinant of the level of expertise. Thus, deliberate practice is a critical process required for the development of expertise or mastery. In an apprenticeship-based model of surgical education, there are fewer opportunities for deliberate practice. This is where simulation can play an important learning function.

2.2.3 The Role of Expert Supervision

Vygotsky, an early twentieth-century Russian psychologist, accurately defined the role of specialists in assistance. He suggested the notion of a "proximal development zone," within which the learner could progress in problem-solving "in collaboration with more capable peers," even if unable to do so independently [20, 21]. Each student's "proximal developmental zone" may vary, requiring different levels of peer support and guidance from the counselor until eventually the skill can be mastered. Some trainees begin at a more advanced proximal development zone, whereas others do not. This idea subsequently was further developed by Bruner [22] who coined the concept of "scaffolding," or temporary learning support afforded by an expert tutor. This involves allowing the learner to progress within his/her proximal development zone with the available help of an expert tutor, who can provide feedback to aid in skill acquisition.

2.2.4 Situated Learning Theory

Lave and Wenger defined learning as an inseparable and integrated aspect of social practice, rather than a process of internalization of individual experience [23]. The essential component of learning, when viewed as an activity, is the process of participation. This means that learners who integrate communities of practice, with the goal of mastering skills, are required to move toward full participation in the sociocultural practices of that community. This social process may include learning practical skills. Participation is crucial in this theory and becomes more and more central once the trainee becomes engaged with peers within the same community. Lave and Wenger highlight that this apprenticeship is not about providing teaching, but about conferring legitimacy [24]. This theory is not directly related to healthcare. However, it may be noted that successful acquisition of skills requires sustained social interaction, which also is usually time-consuming.

2.2.5 Practice and Feedback

Boud [25] and Schon [26] described processes whereby trainees learn from practicing the knowledge, the experiential learning, and the reflection on practice (feedback). Feedback can be a retrospective activity after the skills teaching session, while performing the skill, or after the action. The combination of all feedback processes can maximize the reflection process. Feedback from trainers, as discussed by Ende [27], is as important as the self-reflection from the learners themselves. Feedback is one of the most powerful learning tools and is useful in developing and targeting subsequent steps. It is a crucial component of learning practical skills, as it constitutes interaction within the community of practice.

2.2.6 Learning Affectiveness

The affective component in learning cannot be underestimated although it is often neglected because the cognitive issues always seem to dominate. The affective aspect of learning is powerful and exerts both positive and negative effects on learners' experiences and, in some respects, is critical to the acquisition of psychomotor skills [23, 28]. It is common that some experts often share experiences about mentors that have enriched their professional practice and have affected their professional development and vice versa. Surgical trainees must take ownership of their training, and be responsible for their own development, to achieve adequate skill acquisition. Self-directed learning, feedback, and motivation are crucial.

The hierarchical model in which the physical, emotional, and psychological aspects of the learners need to be solved before effective learning can take place was described by Maslow [29], establishing an essential condition for the learning is the creation of a sustainable and pleasant environment, with the objective of motivating and encouraging participation in the learning process.

2.2.7 Social Cognitive Theory

Social cognitive theory, first delineated by Bandura [30], proposes that people acquire new skills by observing others and modeling. Social cognitive learning proposes that learning has three determinants: personal, behavioral, and environmental. The personal determinant refers to the concept of self-efficacy. The surgeon needs to have a certain confidence in personal abilities to be able to perform well in the operation room. The second determinant of social cognitive theory is behavioral, or the response that the learner receives after completing a behavior correctly. Surgical trainees should be given a chance to successfully demonstrate their learned behavior before being prompted to learn a subsequent unfamiliar task. There is also a belief that allowing a learner to fail in the process of learning a task is beneficial. Productive failure may have some downstream benefits, but only in the right setting and with the appropriate coaching and constructive feedback. The last determinant in Bandura's social cognitive theory emphasizes the environmental aspect of learning. The overall training structure, simulation resources, and mentors are all influential. Interestingly, a study by Baker et al. [31] measured stress in simulation compared to in the operating room and found that simulation did not accurately generate the same amount of stress for trainees. An understanding of the effect of stress in clinical contexts is critical, as stress is known to adversely affect both technical and non-technical skills and could impact patient care. Therefore, it is important to evaluate trainees' stress in different simulated environments to assess stressful triggers and provide feedback as a learning tool.

2.3 Learning Curve

Learning to teach is not commonly part of any general medical curriculum. Like many professional endeavors, teaching by those more experienced becomes a matter of course. With the challenges of delivering clinical care and ensuring an effective educational experience, teaching in surgical education may need a more guided process. This is precisely the point that is made in Chap. 3.

Many surgeons and trainees alike equate surgical training with the technical aspects of the surgical craft, but it is known that there is a multitude of technical and non-technical skills that may be taught and learnt for true professional development [32]. Non-technical skills play a significant role in day-to-day practice and, equally, need to be mastered.

Surgical education and training should be structured [33]. Training refers to the practical aspects of learning the skill, and the education process encompasses the appreciation of the background complexities and knowledge. Both can include technical and non-technical aspects.

The concept of a learning curve was first introduced to predict aircraft manufacturing costs in 1936 by T.P. Wright, but in the past two decades, it has been increasingly adopted in surgical practice mainly after the introduction of minimally invasive surgery [34]. Learning curves graphically represent the relationship between learning effort and learning outcome. It could be defined as the time taken or the number of procedures needed for a surgeon to be able to perform a procedure independently and with an acceptable outcome.

The y-axis of a learning curve represents an outcome of learning, often called the performance index. The x-axis of a learning curve represents the learning effort, usually made up of sequential attempts at a procedure. Learning is defined as an improvement in the performance index with time [35]. The stereotypical learning curve shows a negative exponential relationship that is based on the theory of deliberate practice [18] where the rate of learning progressively slows as an individual gains experience, culminating into an asymptote or plateau. A plateau is defined as a steady state represented by a constant value of the performance index and usually represents an expert performance level that shows no signs of further improvement [35].

Learning curve analysis is very useful in a randomized controlled trial design, as it can aid estimation of the optimal timing for an assessment and may be useful given the variation in learning patterns between different individuals and educational settings.

Systematic reviews have concluded that statistical methods used to analyze surgical learning curves have been mainly descriptive and unhelpful in determining learning parameters [36]. Cook et al. [37] characterized three key parameters of a learning curve: the initial level of performance, the rate of learning, and the level of the expert plateau. Papachristofi et al. [38] identified the importance of the duration of the learning period and used a two-phase model to help estimate this.

Valsamis et al. [35] formulated a method to model the learning curve among real operative data that was effective in deducing the underlying trends in simulated scenarios, which can practically arise in any learning process.

Learning curve analysis enables dissection of the elements contributing to learning and optimizes the targeting of educational resources appropriately. Statistical process control will ensure the evolution of surgeons based on competency assessments [39] while the use of learning curve analysis as an assessment metric may allow educators to detect individuals or groups of trainees that require additional support and can serve as an adjunct for self-regulated learning.

2.4 Barriers to Teaching and Learning Surgical Skills

2.4.1 Experts as Teachers

A significant barrier to the teaching and learning of surgical skills is that it relies primarily on experts to teach and develop instructional materials. Once physicians are able to perform automated processes, procedural knowledge becomes sometimes inflexible, and experts are often characterized as having rigid mental models and perform automated procedures without conscious thought [40]. As a consequence, experts often omit essential information when trying to describe a task because the information is no longer in their conscious awareness. Studies investigating the teaching of complex knowledge have shown that experts unintentionally omit 50%–70% of the information that is needed to accurately describe a task [41]. Although experts demonstrate superior performance in a specific domain, research has shown that this expertise does not always translate into effective instruction for learners, due to automaticity and rigid mental models.

2.4.2 Cognitive Load Theory

One of the barriers to the learning of surgical skills is the limited capacity of our working memory. Cognitive load theory was first described by Sweller [42], which focuses on the role of the working memory in the learning process due to that surgical training is complex and requires the simultaneous integration of multiple sets of knowledge, skills, and behaviors. It aims to develop instructional design guidelines based on a model of human cognitive architecture, considering the sensory memory, the working memory, and long-term memory.

2.4.2.1 Sensory Memory

New information enters our cognition from our senses (i.e., vision, hearing, touch, smell, taste) via sensory memory. All of the sensory systems detect stimuli that are processes and “may” become perceptions if attended to. Most of them enter the sensory memory but do not reach conscious awareness unless they are attended to. Once they are attended, the information is then processed in the sensory memory and then transferred to working memory.

2.4.2.2 Working Memory

Information that is raised to our awareness enters the domain of the working memory. The most important thing to understand about it is that it has a very limited capacity, only being able to retain 3 or 4 "chunks" of information at any given time [43]. Almost all information in the working memory is lost within 10–15 s if it is not refreshed by active rehearsal. Because of that, the working memory tends to combine or "chunk" new information in blocks. It puts multiple elements of information into a single representation according to how those elements relate to each other to reduce working memory load.

2.4.2.3 Long-Term Memory

Once the working memory organizes the information into schema it connects it with related knowledge already stored on the long-term memory. Long-term memory has a limitless capacity in terms of duration and volume and allows us the ability to store information for future use [13].

2.5 Simulation-Based Training

Simulation has proven to be an excellent adjunct to surgical education. It offers a safe environment in which learners can practice a range of clinical skills without endangering patients [44].

Simulation-based training also enables the implementation of the principles of proficiency-based training, which focuses on assisting trainees to reach a specified level of performance and achieve a uniform set of skills required to perform certain procedures. Quantitative assessment of the level of proficiency based on objective metric measurements is important in improving the quality of surgical education [45]. As in all metric systems, the measurement tools used in the assessment of surgical proficiency need to be practical, objective, and reliable to be accepted as standard.

2.5.1 Measurement Tools Used in Simulation-Based Surgical Skills Training

2.5.1.1 Questionnaires

Questionnaires are designed to generate feedback from trainees regarding their personal feeling of comfort or knowledge level in performing a surgical procedure. Although useful, they are also subjective and unfeasible in terms of standardization.

Thus, a questionnaire is not a suitable measurement tool for validated, standard, and metric assessments of surgical competence [46].

2.5.1.2 Objective Structured Assessment of Technical Skills and Global Rating Scales

The Objective Structured Assessment of Technical Skills (OSATS) is an assessment model of testing surgical skills or task performance in surgical simulation through direct observation of trainees performing a variety of structured operative tasks [47]. It has been developed as a bench-station examination that measures technical performance using standardized portions of procedures outside the operating room. It is done by independent observers who evaluate the trainee's performance using a checklist consisting of a set of specific surgical tasks. We need to have in mind that the checklist reports whether each step of a surgical procedure was completed but does not measure quality or surgical finesse.

The Global Rating Scale is another commonly used surgical skills assessment tool used to measure characteristic surgical behaviors during the performance of a procedure [48]. It provides a comprehensive assessment, which includes objective and subjective criteria and measures non-technical cognitive skills, such as decision-making, finesse, or judgment. Although it was developed as a complement of the objective structured assessment of technical skills, the vast majority of researchers include the Likert-scale assessment tool as the primary component. Over the last two decades, evidence demonstrates that the validation evidence in the inter-rater reliability of OSATS Likert scales is fundamentally flawed with increasing evidence of low levels of inter-rater reliability [49–51].

2.5.1.3 Motion Tracking

Objective assessment of performance with simulators requires metrics to provide accurate measurement of surgical skills. The most used metric measurement methods include task completion time and accuracy, although they may not give all the information needed to certainly evaluate the grade of expertise of the surgeon as it does not supply metric information about the fluidity of hand movements when performing a task. Motion tracking appears to be an objective and valid tool for assessing surgical skills in terms of precision and economy of movement during the performance of surgical procedures [52, 53]. Motion tracking systems can be mounted to surgical tools and attached to or worn on the hands as sensors to differentiate between subjects with different expertise levels.

Hand tracking data appear to confirm that skilled individuals demonstrate a shorter path length, make fewer movements, and took less time to perform the operation, but with the caveat that this improved performance (reduced time, lesser movements, etc.) is not accompanied by an increase in errors. Indeed, this is the precise measurement strategy that underpins many virtual reality (VR) simulations.

However, hand-tracking measurement on its own could lead to incorrect conclusions. For example, a surgeon may show a shorter path length, less time to perform the procedure, and made fewer hand movements because they omitted significant parts of the operation! Good VR simulation has overcome this problem by also reporting the "errors" that the operator enacted or steps they omitted, thus their performance can be judged in context. Using hand-tracking data without this contextual information could be misleading.

2.5.1.4 Video Recording

Video recording of the procedure for later assessment of surgical skills has several advantages, as it can give feedback to the trainee and multiple evaluators can examine the same video recording and score the performance, which may be effective in reducing bias [54].

Uncoupling the task of assessment from the need to be present in the operating room by reviewing videotapes is an important step forward in improving the feasibility of operative assessment. It enables the evaluators to view the operations on their own time schedules and also enables for the use of fast-forwarding, considerably shortening the time demand, while using expert judgment to decide what to view in detail.

On the other hand, editing the videotapes to remove "confounding" sections having a limited view of the procedure can lead to errors to the ratings. By editing out portions of the procedure, subtleties of the performance can be lost to assessment. Therefore, to reliably edit videotapes, there must be some agreed-on standard of what parts of the procedure are necessary for evaluation. Furthermore, criteria must be developed for deciding how to extract the parts of the procedure that are necessary for evaluation from the whole performance [55].

Video recording is valuable not only for the initial training of a novice or for training an experienced surgeon in a new procedure, but also for the maintenance of certification in periodic assessments.

Video recordings from cameras positioned in the operating room or simulation centers can be valuable additions to the surgical skills assessment of almost any type of procedure to show the instrument handling and the surgical field.

A standardized quantitative review of video-recorded procedures can serve many purposes, such as life-long learning with self-assessment for improvement and quality assurance for risk management, as well as for research.

2.5.1.5 Metrics Measurement

The units of performance that have been identified and validated as integral to skilled task performance are the metric units of task execution. These units must be defined so that they can be scored. These metric units should capture the essence of procedure performance and might include the steps that the procedure should be performed in, the instruments used, and what should be done with them [45]. The operational definitions of metric units need to be unambiguous since they need to describe what or not should be done and the order in which it should happen. They should also target performance errors for reduction of them.

Measuring a concrete aspect of a skill using universal metric measurements holds promise for improving reliability, validity, clinical relevance, and applicability in large-scale studies or high-stakes board examinations while reducing time and expense [46]. Metric measurement parameters are critically important in the assessment of surgical skills. It can facilitate training, assessment and allow learners to progress in their training based on their proficiency, rather than the number of cases performed or duration of practice.

The task analysis stage of the development of a simulation is crucial as metrics are the fundamental building blocks of a good training program. Therefore, metrics define how the simulation should be characterized and performed by the trainee and must afford the opportunity for meaningful performance assessment [45]. Validated metric-based simulations can serve as benchmarking devices to carry out proficiency-based training programs.

2.6 Summary

Surgical education has evolved over the last three decades due to changes in surgery starting with the adoption of minimally invasive and image-guided surgical techniques. It has therefore driven change in the traditional approach to the teaching and in the acquisition of new surgical skills, both technical and non-technical. Always considering the educational theory principles, the simulation will undoubtedly play a crucial role and will become a basic step for assessing certain skill competencies before progression to real-life scenarios. It will enhance the development of skills, knowledge, and attitudes generating a new generation of successful medical trainers and learners.

Key Points

- The changing climate of surgical education with the adoption of minimally invasive and image-guided surgical techniques has led to a reinforcement of interest in the process of learning and acquisition of new surgical skills.
- Surgical education and training should be structured.
- Learning theories are essential to developing scientifically solid educational methods.
- Simulation plays a crucial role in surgical education, becoming a basic step for assessing certain skill competencies before progression to real-life cases.
- Proficiency-based training focuses on reaching a specified level of performance and achieving a uniform set of skills required to perform certain procedures.

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Chapter 3
Role of a Surgeon as an Educator

Nicholas Raison and Prokar Dasgupta

3.1 Introduction

Clinicians have always played an important role in training future doctors; however, historically this has been a largely informal and ad hoc role. More recently, while surgical training programs have been formalized, training was still reliant on apprenticeships led by the consultant surgeon. Concerns regarding this system and its suitability in the current era have led to growing calls for reform. Indeed, a report by the General Medical Council (the UK supervisory body for doctors) in 1993 highlighted the poor conditions in which medical students were taught. The report identified problems such as bullying, discrimination, harassment, poor supervision, and poor role models together with concerns about patient safety. Furthermore, while difficult to quantify, studies have shown that the quality of medical training does have downstream effects. Medical school and post-graduate training have been associated with the quality of care, prescribing patterns, use of resources, and even complications years down the line [1].

Historically the surgeons' role as an educator has often been informal. As doctors gained experience and seniority, they would be given greater teaching responsibilities extending to leading teaching at associated medical schools and even pastoral care for medical students. Yet there were few requirements for any formal qualifications or training for such roles with the emphasis placed on clinical and academic achievements. A better understanding of educational theory in medicine

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and increasing pressures on health systems have driven developments in medical training, especially in surgery. As a result, the informal, "amateur" surgeon educator is becoming outdated. Instead trained and experienced surgical trainers are needed to deliver the surgical curriculum that is required to ensure the next generation of surgeons have the necessary skills and training.

3.2 A History of the Surgeon Educator

The modern surgeon must fulfill various duties beyond the treatment and care of their patients. Increasingly they are needed to support the efficient running of their services as administrators and managers. Surgeons must also maintain a role as clinician-scientists keeping abreast of scientific developments relevant to their practice and undertake research themselves. Finally, surgeons are expected to educate and train. Indeed, the position of a surgeon as an educator remains an important and central responsibility. Education is recognized as one of the key roles of any doctor. The General Medical Council highlights this as a principle duty for all doctors: "Whatever their role, doctors must do the following…. Contribute to teaching and training doctors and other healthcare professionals."

The role of the surgeon educator has a long history. Apprenticeship training has historically always played a central role in western medical education. Up to the nineteenth century, medicine remained relatively clearly divided between the academic physicians and other more technically trained practitioners such as surgeons, apothecaries, and tooth extractors. Physicians were trained in medicine (or physic) in the new universities that had arisen from the monasteries and traditional seats of learning across Europe such as Padua, Leiden, Oxford, and Cambridge. A theoretical curriculum based on the works of Galen was taught with limited practical applications. Anatomical dissections, when performed, would only be used to demonstrate Galen's often incorrect teachings rather than for any greater scientific benefit. In contrast, other medical practitioners such as those mentioned above would learn their trade through an apprenticeship model. Apprentices would often pay to be indentured to a master craftsman. Training took several years during which time the apprentices would be expected to undertake various menial tasks and errands as required by their master. The content and structure of the training were determined by the various guilds. Consequently, both study time and the specific training requirements varied considerably. Over time there was an expansion in the regulation of medical training with the government playing an increasingly important role in licensure of the profession trade. In England, in 1518, Thomas Linacre established the Royal College of Physicians together with medical chairs at Oxford and Cambridge.

The early nineteenth century saw a major change in medical education. Students would initially undertake a course of lectures or a formal medical degree depending on whether they wished to become a physician, surgeon, or apothecary. This training remained largely theoretical. Practical training was undertaken in subsequent clerkships or apprenticeships which were increasingly completed in hospitals. By 1830, clinical training could be undertaken at one of seven teaching hospitals in London or in Edinburgh, Aberdeen, or Dublin [2]. For a fee, students would become apprentices to physicians, apothecaries, or surgeons in teaching hospitals often following a period of training with provincial practitioners. For those who could afford it, it was also possible to become a dresser or "cub" to a leading hospital surgeon or physician. They would assist in surgery, see new patients, and be on call. Training could vary considerably according to the inclinations of the master. Over the course of the nineteenth century, medical schools increasingly took on formal roles of training "doctors" both pre-clinically and clinically. However, the lack of a standardized curriculum and disparities in training received resulted in the UK in the formation of the General Medical Council in 1858. Major concerns included the prioritization of theoretical over practical training and wide variations in admission and licensing bodies. A report by the GMC's Education Committee set out a curriculum for medical training lasting 5 years with specific requirements for chemistry, physics, and biology but little increase in clinical training. In contrast, a significantly more refined and modern system was being practiced in Germany and across the wider western world. Originally developed in the eighteenth century by Herman Boerhaave, Professor of Medicine at the University of Leiden, the German system became widely recognized as at the forefront of medical education. It consisted of close integration between the basic sciences and clinical medical training alongside a relatively structured clerkship program. Teaching was coordinated by full-time academics and intense competition was fostered among trainees with only the best and most dedicated progressing to a position working with the professor. Most famously this system of training was developed further and introduced to John Hopkins Medical School by William Halsted. Halstedian training, which has now become synonymous with the apprenticeship model of medical education, focussed on the graduated responsibility given to trainees as they gained experience alongside intense and repetitive opportunities for treating patients and an understanding of the scientific basis of disease. Less well known is the intense competition fostered by Halsted, with only a very few of the best trainees progressing to become residents and his uncompromising approach to standards [3]. Trainees had to be available any time of day or night 365 days per year and there was no set length to training with Halsted deciding when a trainee was ready to practice [4].

The Halstedian system of a structured residency program continued to be used for over a century. While being criticized for the long, onerous hours, especially in surgery, it remained an effective approach for training competent clinicians.

More recently various factors have meant that this training model is increasingly questioned. Around the world, overly long working hours, even in medicine, have been deemed unacceptable both for the health of the workers as well as concerns over errors and safety. Changes were made to the maximum working hours, most notably in Europe with the introduction of the European Working Time Directive that limited all workers to 48 h per week with further controls on rest periods. Similarly, working hours were reduced in the USA with guidelines reducing medical trainees to under 80 h per week.

Another major influence on surgical training has been the increasing concerns over medical errors and complications. Expectations for zero-complication surgery have led to the expansion of safeguards, standardization of practices, and ever-greater scrutiny of surgical outcomes. Publication of the report "To Err is Human" highlighted that 10% of hospital patients suffered a complication led to the increasing evaluation of clinical training [5]. In the UK, this issue has been highlighted by the publication of surgical outcomes for a number of specialties. As a result, the effects of learning curves on surgical outcomes, specifically with regard to trainees, have been carefully scrutinized. Progressive pressures on healthcare budgets have been another factor in the drive of change in medical education. The combination of the rising demand for healthcare as society ages together with increasing healthcare costs is putting ever greater strain on limited resources. As a result, there has been a persistent and growing effort to build greater efficiencies in health systems optimizing the allocation of resources and reducing waste.

In response, medical education has started to undergo a major change, building on educational theory developed in other disciplines. Until recently, there was little research on the process of surgical skill acquisition. Out of the Halstedian model of surgical apprenticeship, a three-stage process was broadly adopted for surgical skill training. Initially, trainees would just observe a number of surgical procedures. In the second stage, they would perform the techniques under close supervision. Finally, in the third stage, they would undertake a more independent role as the main surgeon [6]. While not an accurate description, this process is widely known by the phrase "see 1, do 1, teach 1." However, it has been recognized that for safe clinical practice and efficient surgical training, surgical training needs to be performed in a dedicated environment and often outside the operating room away from "real" patients. Another important development has been the realization of the importance of focussed training. Achieving aptitude in everyday tasks to an acceptable level such as learning to drive or play recreational golf is relatively easy to achieve with limited training and practice. It has been estimated to take less than 50 hours for most skills [7]. At this stage, an automated state is reached in which the task can be executed relatively smoothly with infrequent errors. In contrast, it is now recognized that the development of expertise rather than just aptitude in a particular skill or field is not solely the product of the length of training or amount of experience. Rather it requires focussed, repetitive, and effective practice.

To meet these new challenges, the role of the surgeon educator has also needed to evolve and diversify. Not only must they impart knowledge but also act as an effective facilitator, planner, and assessor. As result, there is an increasing realization that medical education is a specialist skill that requires specific training and ability. While desirable that trainers be experts in their fields, expert surgeons are not necessarily expert teachers. Instead, surgeons need the training to help them meet the needs of their trainees and ensure that they gain the necessary skills to become safe independent surgeons.

3.3 The Learning Environment

For surgical training, in particular, the learning environment is essential for effective training but poses significant obstacles. Despite the numerous barriers to learning in the clinical environment such as clinical workload pressures, understaffing, and overcrowding, learning in a clinical context remains fundamental to surgical training. Simulation has, to a large extent, been able to optimize training, particularly for non-technical and technical skills by moving learning to a dedicated space optimized for learning. Yet at some stage, all clinicians must learn how to manage real patients in real clinical environments. It is essential that the surgeon educator can manage training in the clinical environment safely and effectively.

The increasing use of technology is also having an increasing impact on all aspects of healthcare delivery. The modern trainee is adept at using electronic resources and technology for learning. Having grown up in a digital world, they are accustomed to using technology to augment both their training and clinical practice. Learning resources are available digitally almost anywhere. However, while the Internet provides instant access to information on almost any topic, the quality of this information is less reliable. Evaluating the quality as well as the content of information has become an essential skill. This is especially important for the increasing amount of informal educational content developed by online communities without formal peer reviews such as blogs or podcasts [8].

Another major impact of technology on healthcare delivery and training has been the evolution in communication. Digital communication tools like instant messaging, email, and remote access to digital records means that clinical decisions can now be discussed and decided remotely. This has helped increase efficiency and also arguably increased the involvement of supervising surgeons. On the other hand, digital communication has replaced a lot of face-to-face contact which has the potential to reduce learning opportunities. Learners must also be cognizant of the limitations and perils of using digital media in healthcare. Data protection and privacy rules must be safeguarded and surgeon educators have an important role in ensuring that digital resources are used appropriately.

The surgeon educator must be able to respond and adapt to these new challenges. Educational practice is moving away from the more traditional methods of teaching involving less interactive and more didactic teaching techniques such as disseminating information through lectures and demonstrations. Instead, the current student expects and is familiar with a more interactive learning environment to which they are encouraged to apply their own learning style and even objectives. The surgeon educator in particular is faced with the challenge of teaching not only on the wards but also in the operating theater. With clinical pressures, it is becoming increasingly unfeasible to learn basic surgical skills in theater. Simulation tools have been shown to be effective and useful training adjuncts; however, their formal integration into training remains limited [9]. Access to simulation facilities is limited and sporadic;

however, surgeons should strive to incorporate simulation training into their teaching wherever possible. Non-technical skills are another important area for every surgeon requiring directed training (more details in Chap. 17).

3.4 Competency-Based Medical Education

A further challenge for the modern surgeon educator has been the introduction of competency-based medical education (CBME). Previously medical education was centered around a time-based curriculum in which at certain time points, knowledge acquisition had to be demonstrated through formal, high-stakes assessments. These comprised written and practical examinations. Education, particularly in the early stages of clinical training, would focus on disciplines and subjects individually with little integration between topics. In contrast, CBME aims to integrate training both horizontally and vertically. Rather than time-based, training focusses on ensuring that the necessary competencies required for safe and successful clinical practice have been achieved irrespective of the length of time it takes to achieve. The ultimate aim of CBME is to be vertically integrated across pre- and post-graduate medical training schemes. Furthermore, training should also be integrated horizontally moving away from the current focus on knowledge toward a critical competency that spans knowledge application, technical and non-technical skills. Silos of learning such as the historical focus during medical school training when basic sciences such as biochemistry and molecular biology are taught in the classroom before students embark on clinical training are removed. Instead, learning focusses on a clinical problem that spans several disciplines and requires a more integrative approach to learning (Fig. 3.1).

Alongside these changes to the structure of training, CBME also requires a change to the content of the surgical curriculum. A broader range of objectives needs to be met including communication skills, professionalism, leadership and management, and quality improvement. The role of surgeon educators in supporting and facilitating their trainees' progression to safe independent practice is even more important. As training moves away from set assessment points that confirm (or not) competency like the final examinations at the end of the training, the responsibility lies on the individual surgeon trainers to assess and provide the necessary assessment that their trainees are competent across all the domains set out in the new educational framework.

A major driver for the implementation of CBME is to ensure that future doctors meet the needs and demands of their patients. Surgeons are expected not only to be safe and knowledgeable clinicians but must be an expert communicator, professionals in their practice and active in driving system improvements. Demonstrating the necessary professional development is a critical part of a progression.

Another major development in CBME is the transition from the subject and teacher-centered training to education being learner-centered. The learner is required to take ownership but the trainers also have an important role. Instead of focusing

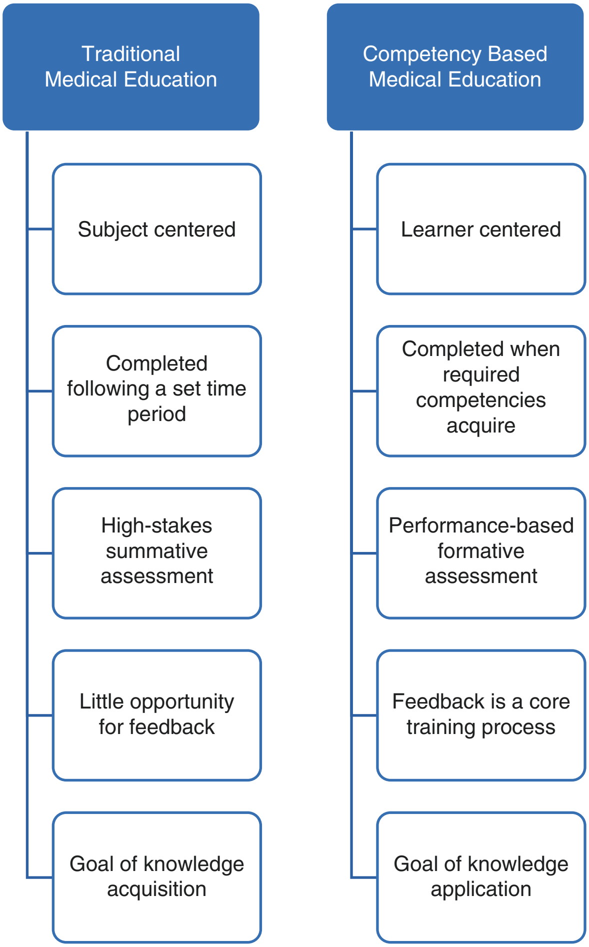

Fig. 3.1 Comparison of traditional and competency-based medical education

on providing knowledge, the surgeon educator should aim to foster a conducive learning environment ensuring the trainee gains the correct experience and provide appropriate feedback. This collaborative approach to learning contrasts with the hierarchical teacher–student model previously used.

One of the main limitations of CBME is the extra resource requirements both on the overall health system and more specifically the surgeon trainers. In comparison to the time-based training, there is more emphasis on learners gaining the necessary experience to achieve the required competencies and importantly, being able to demonstrate this in their practice. As a result, the balance between clinical care and training needs to be refocussed and the time allocated to non-educational commitments is reduced. Secondly, the greater focus on demonstrating competencies through work-based assessments places significantly greater demands on the surgeon educators. Effective assessment requires surgeons to be able to commit the necessary time to observing, assessing, and giving feedback. Furthermore, while recent graduates will be familiar with such learner-centered, competency-based training, it is likely that more senior surgeons will be experienced in the teaching or assessment of the wider domains.

3.5 Proficiency-Based Training and Deliberate Practice

Particularly for technical skills, effective training requires more than just repetitive practice. Trainees should focus on developing the particular skills in which they are deficient rather than learning being dictated by caseload and patient availability. A central concept for effective training is deliberate practice. Introduced by Ericsson, deliberate practice is characterized by a highly structured, goal-orientated approach to training. The topic is further discussed in Chap. 6. The advantages of proficiency-based training in driving skill acquisition over historical models of experiential learning are widely recognized in medicine; Halsted was an early advocate [10]. While experience is often still considered synonymous with expertise, increasingly goal-directed, focussed training forms the basis of curricula across the spectrum of specialties [7]. It is based on a number of key principles; motivated learners; repetitive performance of a particular task; well-defined objectives addressing relevant skills or topics; effective assessment with reliable data, informative feedback and performance evaluation [11]. Ericsson demonstrated that specialized training and feedback provide the optimum conditions for nurturing performance improvement. Furthermore, it is hypothesized that deliberate practice is the key driving force in developing expert performance over both innate ability and extended experience. Studies have demonstrated the effectiveness of deliberate practice and shown it to be substantially superior to traditional methods of clinical training in a range of disciplines. Deliberate practice is also often combined with mastery learning. This can be characterized as a competency-based training model in which skills and knowledge are rigorously tested in relation to a high standard beyond that of competency alone without any restriction on training time. The aim is to achieve uniformly high training outcomes although training time is expected to vary among participants. Mastery learning requires established, evidence-based minimum standards, baseline assessment, targeted instruction, reassessment, and progression based only on attainment of the pre-defined standard. When performed correctly, mastery learning has been shown to be associated with higher outcomes than non-mastery learning.

A critical component of mastery learning and deliberate practice is accurate performance evaluation. Assessment before and after training is important to ensure that the necessary standards have been achieved and that training has been successful. Evaluation is also important for training in itself: feedback to learners helps to direct their learning, aids motivation, and provides a standard against which progression can be checked. Feedback was identified in a review of clinical training as the most important feature for simulation-based medical education. Yet feedback needs to be understandable, relevant, and usable for the trainees.

3.6 The Attributes of the Surgeon Educator

While expertise in the field is naturally an important requirement for trainers, personal attributes also play a role. Various studies have investigated which attributes are deemed to be important by both trainees and trainers. While there are discrepancies between the two and across studies, there are a high number of characteristics that are regularly mentioned covering various domains (Table 3.1).

As can be seen in Table 3.1, the key attributes focus on a variety of domains as identified by trainers and trainees from a number of studies [12, 13]. They are in general relatively generic qualities, also important for being a successful surgeon, and are very antithesis of the characteristics in the Tomorrow's Doctors Report. It is often noted that excellent teachers are also excellent clinicians. Indeed, the role of training in improving clinical care remains greatly underappreciated especially by hospital administrators.

3.7 Teaching the Surgeon to be an Educator

The value of formal training for clinical teachers is being recognized. That such teaching training is being incorporated into most training programs further demonstrates the central role of teaching in medicine.

In response to the many challenges that now face the surgeon educator, in addition to the recognition of the importance of surgical education, specific training courses in education and teaching have been developed, such as "Train the Trainer" courses.

Table 3.1 Examples of the key attributes of a surgeon educator

Leadership	Conscientious
	Patient
	Behaves as a role model
	Inspires
	Motivates
Communication	Enthusiastic
	Honest
	Kind to patients
	Mindful
	Reflective
Professionalism	Available
	Honest
	Respectful
	Inspiring
	Good relationship with colleagues

In time-based curricula, training would focus on core knowledge-based learning. Domains outside standard surgical expertise like communication or leadership were often learnt by observation and "osmosis." End of rotation or end of training assessment would then confirm that the trainee has gained the necessary skills. In contrast for CBME, such training needs to be explicit and trainers need the expertise to teach and assess these competencies. A sound understanding of the principles and objectives of CBME is therefore critical. Essential elements for transitioning to CBME include demonstrating compassion and respect for others, using technology to optimize learning and effective communication [14]. For surgeons who will not have encountered these learning styles in their own training, faculty development is important to ensure they remain proficient trainers, especially with the newer emphasis on "touchy-feely competencies" ignored by older education systems [14].

Numerous courses are now available for both generic training and specific environments; for example, robotic surgery. Generally, "Train the Trainer" courses aim to provide both a background to learning theory, in particular CBME, as well as more practical instruction on teaching technique, feedback, assessment, communication, and related topics. Following training, it has been found that clinicians not only change the content and style of their teaching but that they also express a greater motivation and interest in teaching [15]. For more specialized teaching training like in robotic surgery, the courses offer more specific guidance on training techniques including technical and non-technical skills, how to maintain safety when teaching, and incorporating assessment tools [16]. Also important is the teaching in educational concepts and principles both relating to teaching structures but also wider skills such as stimulating reflection, assessing trainees needs and feedback. Beyond individual training courses, ongoing support for trainers is also important. Often provided by national bodies, such initiatives help drive system-wide engagement in training and maintain teaching standards by individuals and their institutions.

3.8 Innovators in Surgical Education

The development of surgical training is increasingly being led by surgeons. Based on the educational tenets as discussed above, training programs across surgery are being devised to support the next generation of surgeons. These include both national and international collaborations often working with surgical associations as well as local programs. Such initiatives benefit from applying evidence-based training methods for training and setting validated competency standards [17]. The majority of surgical specialties are building their own training programs and systems of quality control for all trainees from basic to advanced, subspecialty skills. In addition to developing and delivering these education programs, surgeons have taken the lead in their assessment and validation. Numerous large, randomized controlled trials have been completed showing the effectiveness of the new evidence-based surgical curricula. Urologists in particular have demonstrated the feasibility of completing multicenter trials with supranational collaboration. The results of the SIMULATE trial evaluating a simulation-based curriculum for ureterorenoscopy are eagerly awaited [18]. Similarly, the multi-institutional validation and assessment of training modalities in robotic surgery (the MARS) project, working with institutions across Europe has helped develop a structured training program for robotic surgery [19]. Utilizing an international, multicenter approach, the MARS project developed a template for training basic and advanced robotic technical and non-technical skills.

Including surgeons in the establishment of new training programs is important. They offer a unique insight into both the training that is required and also how this can be effectively delivered. Furthermore, surgeons are now increasingly taking the lead in applying educational theory to the clinical environment, driving the inclusion of modern educational theory in surgical education.

3.9 Summary

The role of the surgeon educator has undergone substantial changes in recent years promoting a drastic re-evaluation of this traditional role. Major challenges in the delivery of safe and effective healthcare as well as changes in working practices mean that the older models of training are increasingly being recognized as no longer suitable. In response, there is a greater drive for implementing best practices in medical training to ensure that training remains safe and efficient in spite of these challenges. As a result, the role of the surgeon educator is also evolving.

Modern clinical environments and practices mean that opportunities for "on the job training" in surgery are becoming increasingly rare. Limited surgical exposure means that simulation tools need to be used to supplement technical and non-technical skills training. These allow training to be moved to more conducive environments maintaining patient safety and enabling trainees to focus on the acquisition of the necessary skills. The transformation of healthcare by technology has also had major effects and an important aspect of training is how such technologies can be safely utilized and navigated. Wider developments in education have now started to be incorporated into medical training. Moving toward a competency-based system appears to make training more effective and improve outcomes. However, it comes with extra burdens on both surgeon trainers and the whole health system to provide the necessary experience for training.

In response, there has been a significant professionalization of surgical educators, with trainers becoming increasingly qualified and dedicated to training. As a result, surgeon educators not only deliver but also create and develop training programs. The shift from the apprenticeship model to an organized and structured curriculum is being driven by surgeons. As a result, there is an increasing need for trainers to be able to dedicate significant portions of their time to education. Dedicated training is often now obligatory and there has been a large growth in the number of medical educationalists in universities and other institutions. To ensure that future surgeons have the necessary skills to continue to provide high-quality care, today's surgeon educators need to embrace these changes and continue to strive for excellence in training.

Key Points

- The master–apprentice model for surgical training is being replaced by a CBME approach.
- Use of simulation tools and technology is increasingly being used to improve the effectiveness of surgical training.
- Surgical educators require specific training and support to ensure they have the necessary skills to deliver effective training.
- Simulation training especially when combined with proficiency-based training can be highly effective in delivering technical and non-technical skills training.
- Surgical education must continue to evolve to meet the ongoing needs of patients, trainees, healthcare organizations, and regulators.

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Chapter 4
Proficiency-Based Progression Simulation Training: Shortening the Learning Curve

Marco Amato and Anthony G. Gallagher

4.1 Introduction

Until only recently doctors and surgeons had been trained using an apprenticeship model developed in the late nineteenth century by Dr. William Stewart Halsted at the Johns Hopkins Hospital, Baltimore, USA [1]. Surgeons had traditionally acquired their craft on real patients during long work hours on hospital wards and in the operating room. Before the late twentieth century, most surgical operations were carried out through an open incision and larger incisions usually meant more advanced and complex surgery. Also, the amount of pain and time recovering in the hospital were closely correlated to the size of the incision made by the surgeon. Advances in computers and microchip technology that ushered in a digital age also revolutionized the operating room. The same image processing capability that underpins the camera in mobile phones was used at the end of a thin 30 cm long fiber-optic telescope to look inside patients through a small surgical incision. This new minimally invasive or "keyhole" approach to surgery was used to perform increasingly more advanced surgical procedures as well as robotic surgery [2]. This meant that patients had major surgery performed with less scarring, pain, and time

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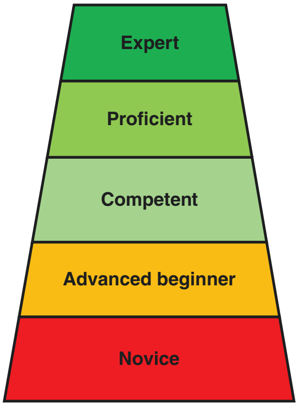
in hospital. However, it quickly became clear that even very experienced surgeons had difficulties acquiring the new and very different skills necessary to perform keyhole and robotic surgery. They had to perform the procedure while looking at a TV monitor that produced images inferior to that perceived by the naked eye under natural viewing conditions and lacked many of the subtle visual cues for judging the depth of field [3]. There were also considerable difficulties coordinating surgical instruments that passed through tiny incisions and which pivoted against the body wall thus giving the impression of counter-intuitive instrument movements on the monitor [4]. Tactile feedback from the tissues being operated on was reduced or, in the case of surgical robots, absent. All of these human-factor difficulties meant that the already difficult job of performing surgery safely was made orders of magnitude more difficult [5].

4.2 Simulation-Based Training

These training difficulties forced the surgical and scientific community to reflect on why this was so and to develop new ways of training. A revolution in computer technology had led to the problems faced by surgeons. This same technology would offer a very powerful training solution. Aviation had used computer-generated virtual reality (VR) simulations to train pilots for decades. However, unlike airplanes and airports with standardized features, real patients are all different. Furthermore, the aviation industry had over decades worked out precise protocols for dealing with different airplanes, airport terrains, and flight scenarios. Surgery in comparison was very much a craft with individual surgeons applying their own art to procedure performance. To utilize simulations for training, surgeons had first to develop surgical procedure templates, including, for example, the individual steps of the procedure and the choice of instruments. They also had to identify optimal and deviations from optimal performance so that engineers and computer scientists could build the simulation and accurately characterize the operation so that performance was quantifiable. Thus, surgical procedures could be learned and rehearsed on a VR simulation before operating on a patient for the first time [6].

4.3 Proficiency-Based Progression (PBP) Simulation Training: What Is It?

Dreyfus and Dreyfus [7] have suggested a model of skill acquisition (Fig. 4.1) that may be applicable to surgery and other interventional disciplines. They proposed that skill acquisition is a developmental process and have identified incremental steps in this process as well as their performance attributes which are shown in Fig. 4.1. Although they have identified performance attributes of each stage of skill, they did not propose operational definitions which are assessable and refutable.



STAGE	PERFORMANCE CHARACTERISTICS
Expert	• Source of knowledge and information for others • Continually looks for better methods • Work primarily from intuition • Being forced to follow rules degrades performance
Proficient	• Seeks to understand larger context • Frustrated by oversimplification • Can self-correct performance • Can learn from experience of others
Competent	• Can troubleshoot problems on his/her own • Seeks out expert user advice • Develops conceptual model
Advanced beginner	• Starts trying tasks on his/her own • Has difficulty troubleshooting • Begins to formulate principles, but without holistic understanding
Novice	• Has little or no previous experience • Does not know how to respond to mistake • Needs rules to function

Fig. 4.1 The Dreyfus and Dreyfus (1986) model of skill development and performance characteristics of each stage of skill development. (From Gallagher and O'Sullivan [8])

They have proposed that during the transition from one skills stage to another there may be a considerable overlap of performance characteristics. Gradually, performance characteristics of a particular stage come to predominate, and the developmental process consolidates and then continues to the next stage of development. The elegance of this proposal is that it can account for micro and macro development of skills and individuals over short and longer periods of time (e.g., learning to perform a new procedure or career development).

Gallagher et al. [5] adopted a proficiency-based progression rather than a competency-based approach to the training of surgeons for a number of reasons. They wished to avoid the incessant and circular discussion and debate over the definitions and measurement of precisely what constitutes "competency" [9–14]. Instead, they opted for a parsimonious quantitative benchmarking based on the concept of proficiency. They have taken as their starting premise that the vast majority of attending/consultant grade surgeons' currently practicing clinical surgery are at least competent, probably proficient, and possibly expert. The next step in their process involved experienced surgeons identifying performance characteristics that are associated with the optimal and sub-optimal performance of a given surgical procedure (i.e., Stage 1a, a task analysis, Fig. 4.2). These performance characteristics or *metrics* are then operationally defined so that they are reliably identifiable from the videotaped performance of operating surgeon's (Stage 1b, Fig. 4.2). The task analysis group also identifies performance characteristics which they consider critical errors. These are knowledge or procedural acts, which if acted upon, considerably compromise the safety of the patient. At Stage 1c (Fig. 4.2), the usefulness and robustness of the metric definitions at capturing and reliably distinguishing the performance characteristic of interest are assessed by applying the metrics and their definitions to video recorded operative performance. During this verification and assessment process metrics and their definitions are honed, refined, or excluded. The metrics should then be presented to a panel of peers (in a modified Delphi

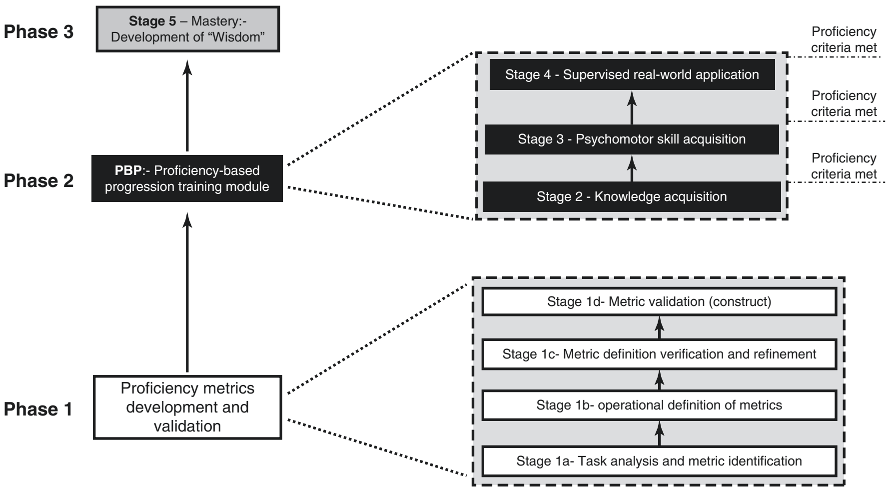


Fig. 4.2 The proficiency-based progression training paradigm as an iterative process applied throughout and within training as well as for skill development for new procedures or new devices. The procedure of interest is first subjected to a task analysis (**a**) and metrics are unambiguously defined (**b**), then verified and refined (**c**) and validated (**d**). Validated metrics are then used to develop and configure the proficiency-based progression training module (Stages 2–4). During proficiency-based training, an individual does not progress until the proficiency benchmark has been demonstrated (consistently)

format) [8, 15–17] to evaluate the accuracy, appropriateness, and correctness of the metrics in capturing the essence of optimal and suboptimal performance of a reference approach (i.e., common, straightforward, and uncomplicated) to the procedure performed. Lastly, the metrics and their associated definitions are assessed for their construct validity (Stage 1d). If the metrics identified during this process have truly captured (at least part) of the essence of experienced operator performance (i.e., proficiency), they should reliably distinguish experienced from novice operator performance [15, 16, 18–29].

The next step in the process (Phase 2) is to use the information developed from the task analysis and construct validation process to construct a curriculum. The curriculum will show considerable overlap with the existing curriculum, but it will put emphasis on performance characteristics that were identified during the previous stages as reliably distinguishing between experienced operators and novices. These will be communicated to the trainee in such a way that the trainee knows what to do and with which instrument during a given procedure (Fig. 4.2, Stage 2).

Furthermore, the trainee may not progress until they have mastered this knowledge to at least the level of the experienced operators (e.g., proficiency benchmarking). This approach has two advantages; (1) it ensures that educators do not establish an unrealistically high pass threshold for trainees but is based on what experienced operators know (and not on what the educators think they should know) and (2) it ensures that during the psychomotor skill acquisition process in the skills laboratory that time is used efficiently and effectively integrating procedural knowledge with the application of surgical technique. The *exception* for the definition and demonstration of proficiency levels by trainees for knowledge and psychomotor skills is that trainees will automatically fail to demonstrate proficiency if they enact a performance or performances that are deemed to be critical errors and identified by the proficiency definition panel as automatic failure events. These performance units have already been specifically identified and defined at Stages 1a and 1b. For example, the technical skill proficiency level established based on experienced operator performance may be three performance errors. This means that to demonstrate proficiency trainees must enact no more than three errors. In the AANA Copernicus study, they suggested that more egregious errors should be referred to as sentinel errors as even these were not life-threatening although they did compromise the safety of the patient or the integrity of the procedure [30]. In this study, they did allow one sentinel error in the proficiency definition, i.e. no more than three errors and not more than one could be a sentinel error. In contrast Cates, Lonn, and Gallagher [31] permitted no critical errors in their PBP training program. The important point is that it is the experienced clinician practitioners who define the proficiency benchmark (based on the mean performance of experienced and proficient practitioners as the starting point) and whether ANY critical/sentinel errors are allowable in the proficiency definition.

eLearning is an important part of the PBP training process. This approach ensures that valuable laboratory-supervised training time is not used for learning basic aspects of a procedure that could have been acquired with a less expensive learning medium, e.g., online learning. The use of an eLearning teaching medium also means that it should be relatively easy for educators to verify that trainees have satisfied the requisite proficiency criterion, how long they took to reach it, and if specific aspects of learning the procedure posed difficulties. This may indicate that the eLearning material may need to be modified or improved but it could also serve to guide trainers on aspects of skills laboratory training that require particular attention (Fig. 4.2, Stage 3). During this stage trainers will have identified an appropriate existing simulation training platform (e.g., or Lap Sim (Surgical Science, Sweden, a box-trainer model) or develop one of their own [25, 32] that trains the appropriate performance characteristics that have been previously identified from the proficiency metrics. The goal of their approach to training is to ensure that the trainee knows what to do, what not to do and can do it efficiently and safely. A performance benchmark should also have been established on the same simulation model that the trainees use for training. The mean of objectively assessed performances of practicing surgeons experienced with the procedure has been used as the starting point for the proficiency benchmark [5, 33, 34]. The methodology has however evolved, and the mean is now the starting point and the proficiency benchmark may or may not include specific mention of critical or sentinel errors. The discussion around the proficiency benchmark discussion will almost certainly involve discussion of atypical performance by some expert/experienced practitioners and the possible exclusion of some scores because they are "atypical" to their peers [35]. Once a proficiency benchmark has been defined, surgical trainees are then required to practice on the simulation model until they can consistently demonstrate the proficiency level.

Stage 4 (Phase 2, Fig. 4.2) involves the supervised application of the knowledge and skill that the trainee has acquired in the operating room on a real patient. Thus, the operating room becomes a finishing school for the trainee rather than a basic skill learning environment. Results from prospective, randomized, double-blind, evaluation of this approach to training show that proficiency-based progression trainees make significantly fewer objectively assessed intraoperative errors than traditionally trained surgical trainees [34, 36–39]. The final stage of the proficiency-based progression approach to training (Fig. 4.2, Phase 3) involves the learner further integrating, honing, and refining their procedural performance which is probably a career-long enterprise which Dreyfus and Dreyfus [7] refer to in their model of skill acquisition as one of the attributes of an expert.

4.4 Proficiency-Based Progression: How to Do it?

There is nothing magical about the PBP methodology. It is simply the application of the scientific method for the development of the performance metrics which best characterize the optimal and sub-optimal performance. The use of simulation models simply means that surgeons can now learn how to perform a specific procedure using the exact same devices, in the exact same way on training models or virtual patients that are based on real cases. In the past, they learned these skills (and made mistakes) on real patients but in the skills lab and on a virtual patient they could perform the exact same procedure repeatedly and learn what not to do as well as what to do. This type of learning with performance feedback is called deliberate [40] practice and constitutes a very powerful approach to training that contrasts with the traditional apprenticeship model where performance feedback and learning was much more hit-and-miss. In 2011, the Department of Health (DoH) proposed that ALL healthcare procedures should be learned this way and a procedure should not be performed on a real patient the first time it is performed [41].

This very meticulous approach to the acquisition of skills for the operating room relies on systematic, simulation-based, learning on models and virtual patient cases for training and education [42]. It means that surgeons (and other health care workers) can be optimally prepared for the operating room with their performance benchmarked against practicing and proficient surgeons before operating on real patients. Research has now shown that surgeons trained using this approach perform significantly better and make fewer errors than traditionally trained surgeons [30, 31, 34, 38, 39] and approximately 40–60% of what is learned on simulation transfers to real-world tasks [43, 44].

Training with simulation, VR, technology-enhanced learning (or TEL), and other learning methodologies ensures learning to a quantitatively defined performance level and greater homogeneity in trainee skill-sets [42]. Evidence from prospective, randomized studies shows that this “outcome-based” education and training produces trainees with skill-sets that are 40–70% better than trainees using a traditional approach to training [31, 34, 38, 39]. These studies also show that trainees who receive the exact same curriculum but without the quantitatively defined performance benchmark perform only marginally better than those receiving traditionally training [30]. Furthermore, similar results have been observed for an outcome-based communication skills training program (e.g., handover) [45]. These results clearly demonstrate that simulation-based training is effective for communication as well as technical skills training. However, simulation training must be more than just an interesting educational experience.

4.5 Evidence of Effectiveness

Quantitative evidence already exists which demonstrates that simulation is a better way to train [26, 29–31, 34, 38, 39, 45, 46]. Results for a systematic review and meta-analysis of prospective, randomized, and blinded clinical studies on PBP training show a ~60% reduction in objectively assessed performance errors in comparison to quality-assured conventional training programs [44]. The application of this approach (i.e., proficiency-based progression or PBP) has already demonstrated the power of simulation to dramatically improve suturing skills [25, 29], laparoscopic surgical skills [34, 38, 39], interventional cardiology skills [31], orthopedic surgery skills [30], and anesthetist skills for childbirth [46]. Recently the same approach to simulation-based training has been used to develop the training curriculum for non-university educated workers whose job is the location and excavation of underground utility services [47]. The results are always the same; PBP simulation training improves overall performance and produces 30–60% reduction in on-the-job errors. This approach to training is now being used for training physicians to perform mechanical thrombectomy in acute stroke [48]. An outline of the theoretical and applied underpinnings have been reported in detail [5, 33, 42]. However, publications on simulation to date have only demonstrated how superficially simulation science is understood by medicine, computer and engineering science, the construction industry and usually rests on procedure-specific or discipline-specific applications. Usually, scant attention is paid to the underlying science and engineering of what makes for effective simulation training.

The Arthroscopy Association of North America reported one of the clearest scientific studies assessing this approach to training in comparison to their "Gold Standard" training. In a multicenter, prospective, randomized, and blinded study of learning arthroscopic skills to perform a Bankart procedure, the Arthroscopic Association of North America (AANA) assessed the difference between proficiency-based progression (PBP) deliberate and repeated practice training [30]. Three groups of senior (PGY 3 & 4) orthopedic surgical residents from 21 Accreditation Council for Graduate Medical Education (ACGME) residency training programs across the USA participated. The results showed that the PBP deliberate practice group outperformed the traditional AANA trained group. They also made 41% fewer objectively assessed intraoperative errors than a simulation trained group which trained for the exact same, time frame, level of faculty trainers and training resources but with a repeated rather than a deliberate practice training curriculum. At the end of the training, 75% of the PBP group demonstrated the proficiency benchmark in comparison to 29% of the conventional AANA trained group and 36% for the other simulation trained group. Furthermore, the PBP trained group were >7 times as likely to demonstrate the proficiency benchmark as the conventional trained group. The result of this study verifies the centrality of performance metrics, derived from and benchmark on experienced surgeons. It is these metrics which make the simulation effective [33, 42].

The reason why the PBP trained group did so well was that they were given metric-based formative feedback on their operative technique as they were practicing their skills. Thus, they were able to optimize their skills during training. Furthermore, they were given a quantitatively defined performance benchmark to reach before training was deemed completed. The "simulation" models were thus used as a tool for the delivery of a metric-based training curriculum. Furthermore, the feedback was structured and constructive and all the faculty were trained to use the exact same metrics and to the same standard. This approach eliminates a lot of the subjectivity from performance assessment. Furthermore, faculty were trained to apply the metrics before the course and were not allowed to train and assess on the course until they had demonstrated how well they knew the metrics and could score them to an IRR > 0.8.

4.6 Shortening the Learning Curve

4.6.1 What Is a Learning Curve?

A learning curve is a visual representation of how long it takes to acquire new skills or knowledge. The term was originally coined by the pioneering German psychologist Hermann Ebbinghaus [49] (January 1850–1909) during his studies of learning and forgetting. He pioneered the experimental and scientific study of memory and is probably best known for his discovery of the forgetting curve. The first known use of the term learning curve was from 1903 Bryan and Harter [50]. They were studying the learning of morse code. In their study of the acquisition of the telegraphic language, they describe a learning curve which had the rapid rise at the beginning followed by a period of slower learning and curved or rounded outward like the exterior of a sphere or circle to the vertical axis (as shown in Fig. 4.3—the dotted bell-shaped curve). Although the learning curve was first described by Ebbinghaus and later by Bryan and Harter the "learning curve" term did not become widely used until described by Theodore Paul Wright. In 1936, he described the effect of learning on production costs in the aircraft industry [51]. He used the learning curve concept to graphically depict the relationship between the cost and output over a defined period of time, normally to represent the repetitive task of an employee or worker. What Wright honed in on was the effect of workers learning to do their job

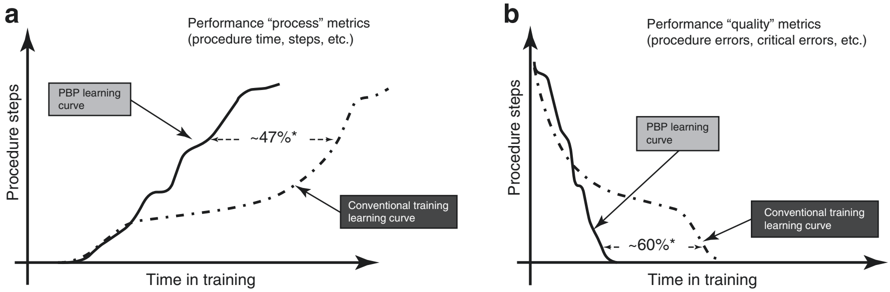


Fig. 4.3 (**a**, **b**) Hypothetical learning curves for conventional training (dotted lines) and PBP training (solid lines) for procedure steps (**a**) and procedure errors as a function of time in training

had on production costs in the aircraft industry and argued (with mathematics) that both were related. Thus, the definition of a "learning curve" has evolved in popular culture to refer to the time and study that it takes to develop knowledge or skills relating to a particular subject or task.

The use and hence understanding of the term "learning curve" really came to the fore with the introduction of minimally invasive surgery. The introduction of minimally invasive surgery, particularly laparoscopic cholecystectomy, was accompanied by an increased frequency of complications, many life-threatening, particularly during the early experiences. That these problems could occur when experienced surgeons, well versed in open techniques and with knowledge of anatomy and pitfalls embraced new techniques, heightened concerns about the training of novices who lacked such a background in open surgery [42]. What this meant was that surgery needed to develop new methods for training the novice in surgical techniques in general and for training experienced surgeons in the newer techniques. Compounding this was a series of high profile adverse medical events (across the world [52–54]) drew the attention of the public to issues of clinical training. The societal response was best epitomized by The Bristol Inquiry in the UK—"there can be no more learning curve on patients" [55]. Surgery was forced to confront realities and to consider new approaches to surgical training—particularly the development and use of simulation to train and develop new techniques and procedures "off-site" in the skills laboratory [56].

The introduction of robotic surgery made almost the exact same mistakes as the minimally invasive surgery pioneers a decade earlier [57]. Despite concerns from multiple quarters about training surgeons to safely use complex technologies such as surgical robotics the initial promise of a comprehensive 6-week training program was subsequently rolled back to a minimum competency training program that was completed in a few days. Even though lawsuits have claimed patient injury because the device manufacturer provided insufficient surgeon training (e.g., Fred Taylor, et al. v. Intuitive Surgical Inc.) [58], the "learned intermediary doctrine" of product liability laws provide an effective shield against these claims. This doctrine indicates that the device manufacturer only needs to provide adequate warnings (not train or instruct on how to avoid harm) to the surgeons because they are considered learned intermediaries.

The irony is that much of the morbidity and mortality associated with learning to use new and complex technologies could have been largely mitigated, had adequate quality assured training been pursued. Much of the training that is offered to trainees across different medical specialties is probably at best an interesting educational experience. Trainees continue to queue to attend 1–5-day training courses, which no doubt considerable thought, effort, and expense have gone into. The simple fact is though, that almost without exception we have no idea what the trainee knows or can do safely at the end of the course. The Angelo et al. [30], Copernicus study is one of the few rigorous evaluations that gives a very clear idea of the trainee's performance capabilities after a comprehensive weekend training course for learning and arthroscopic Bankart procedure. The results showed that less than one third (i.e., 29%) of the trainees demonstrated the quantitatively defined proficiency benchmark at the end of training. The results also showed that the more attractive training condition using simulation models as well as the more traditional training methods had only marginally better training outcomes (i.e., 36%). In contrast, 75% of the PBP trained group which used the exact same curriculum (learning tools, level teaching faculty, time in the skills laboratory, etc.) as the simulation trained group. The difference was that the PBP trained group had to demonstrate a quantitatively defined performance benchmark at each phase of the curriculum (i.e., didactic, suturing and knot tying, simulation model, etc.) before training progression. These results have been mirrored in laparoscopic [34, 38, 39], endovascular [31], anesthesia [46], and communication skills [45]. The results from these types of studies are, on the one hand, very reassuring and on the other extremely worrying. They show that systematic, evidence-based, and quality assured training has a huge impact on the verified performance of trainees at the end of their training course. Conversely, the results also probably indicate how ineffective current training courses are.

Compounding these findings is a relatively recent quantitative demonstration of how much surgical skills impact on morbidity and mortality. Over the decades, some of our more senior colleagues have in polite conversation minimized the causal impact of surgical skill in morbidity and mortality. They have quite rightly argued that the skill of the operating surgeon is only one of a myriad of factors, e.g., decision-making, surgical team, communication skills, etc., which impact on clinical outcomes. At a superficial level, this analysis might seem to make sense and we have no doubt that all these factors significantly contribute to good clinical outcomes *but* at different stages of the patient care pathway [59]. What is more difficult to accept is that the skill of the surgeon might simply be just one of the factors. After all, the surgical procedure performed by the surgeon forms a central core feature to the care pathway of the patient.

Findings from the Birkmeyer et al. [60] study unambiguously addressed this issue. In this study 20 senior and practicing bariatric surgeons submitted a video recording of them performing a laparoscopic gastric bypass procedure. Their performance on the video recorded procedure was objectively assessed by their peers,

Table 4.1 The morbidity and mortality rates (and % difference) of bariatric surgery outcomes associated the surgeons whose surgical skill was assessed as being in the first or fourth Quartile

	1st quartile ("worst") %	2nd quartile	3rd quartile	4th quartile ("Best") %	Prob. level	% difference
Surgical complication rates	11.4	–	–	4.2	0.001	63
Re-admission rates	6.3	–	–	2.7	0.001	57
Re-operation rates	3.4	–	–	1.6	0.001	**52**
Infection rates	4.6	–	–	1.04	0.001	77
ALL complication rates	14.5	–	–	5.2	0.001	64
Mortality rates	0.26	–	–	0.05	0.01	**81**

blinded to the surgeon performing the procedure. Based on this assessment the surgeons were banded into four quartiles, i.e., those that were performing worst (1st—the bottom quartile), two middle quartiles, and those that were performing best (fourth and top quartile). All the patients whom these surgeons operated on over the subsequent 6 years were monitored for procedure outcome. Table 4.1 summarizes the main findings of the 30-day outcomes from the study. Not surprisingly the surgeons who were assessed at the outset of the study as demonstrating the "best" operative skills had significantly lower morbidity and mortality. This probably was not the most surprising finding from the study. After all, outside of medicine, it is logical to predict that more skilled performance will inevitably lead to better performance outcomes. Indeed, the most surprising finding of the study was the magnitude of the difference between those surgeons in the first quartile (i.e., performed worst) and those in the fourth quartile (i.e., performed best). The *smallest* difference between the two groups was on reoperation rates: the data show that those surgeons performing best had a 52% lower reoperation rate. Overall, in this study the mortality rate across the 6 years of the study was low. The data did however demonstrate that a significant difference was observed between the mortality rates of surgeons in the first and fourth quartiles. The surgeons in the first quartile had an 81% higher mortality than surgeons in the fourth quartile.

In a subsequent report, Birkmeyer and colleagues [61] reported outcomes on these patients at 1 year. The results showed that the skill of the surgeon did not predict clinically important outcomes such as weight loss. Some of our colleagues point to this report as evidence that surgical skills are unrelated to clinical outcomes. It is our opinion that this is a misinterpretation of what the results from both of these studies are telling us. The first study [60] unambiguously demonstrates that surgical skills impact on 30-day morbidity and mortality. The second study [61] suggests that if the patient survives in surgery, their clinical outcome at 1 year is unrelated to the skill of the surgeon. The outcome from the surgical procedure is in no small part dependent on this skill of the operating surgeon. Clinical outcomes at 1 year are probably more dependent on other factors such as dietician support, psychological support, weight-loss program, etc. Furthermore, the findings of surgical skill being related to clinical outcomes has since been replicated for cancer surgery [62].

The unavoidable conclusion from these studies for surgery and all of the procedure-based medicine is that clinical outcomes are directly related to the operating skill of the doctor performing the procedure. This does not minimize the central role and function of the OR team, communication skills, equipment, etc. It does point to the central importance of the operating skill. In turn, this underlines the imperative of skills training and the requirement to ensure that training does actually mean something for the trainee.

4.7 Is a Learning Curve Inevitable?

Surgical skills impact on clinical outcome. One or two decades ago, we might have predicted that surgical skills accounted for 5–10% of the difference between operating surgeons. The findings from simulation studies indicated that PBP training produced 40–60% better skills than trainees attending a conventional training program. Even simulation enthusiasts believed that most of this observed performance difference would probably disappear when implemented in a realistic clinical environment. It was difficult for researchers to believe the magnitude of the difference that skilled performance had in the real clinical context, in contrast to the impact in a well-controlled randomized study. The Birkmeyer et al. [60] study acted as a reality check to simulation researchers. The differences that were being observed in well-controlled, randomized, and blinded clinical studies of PBP simulation training did appear to be mirrored in clinical studies on surgical skills.

These speculations continued and remained unanswered until a small-scale, well-controlled, randomized, clinical study from Cork University Hospital was reported [46]. The authors described two training programs to prepare anesthetist residents for the administration of epidural analgesia during labor. The primary outcome measure for the study was epidural failure rate. They observed a 54% reduction in the epidural failure rate (on real patients in the deliver suit) for the PBP trained group in comparison to the simulation trained group [46]. Although small-scale, this is the first study to demonstrate that PBP training impacts on performance skills and that these in turn impact on clinical outcomes. What this study seems to indicate is that PBP training *does* impact on the learning curve.

Figure 4.3 shows what we believe is happening. The curved dotted line shows what we know (from other studies on learning skilled performance) is the learning curve for a conventional or traditional trainee. They show the initial skills/performance acceleration that plateaus and shows only modest improvement for some time, before accelerating again. In contrast, the PBP learning curve (solid line Fig. 4.3) continues to accelerate for the number of procedure steps. Conversely, the number of procedure errors shows a similar pattern (Fig. 4.3b) and reduces at a sharp rate and much faster than the conventionally trained individuals. The Conventional training Group shows a sharp and steady decline in procedure errors that slows down after a period only to accelerate again later in the learning curve of the trainee. In contrast, the PBP trainees and their learning curve show a steady and steep decline from the start of training. Based on a systematic review and meta-analysis on studies that compared conventional training to a PBP approach we can also estimate the difference in the two groups [44]. The results showed that procedure "process" metrics such as time demonstrated a 15% difference between groups. They also showed that procedure Steps (which is also a measure of process rather than quality of performance) increased by ~47% in comparison to the conventionally trained group. Process metrics such as procedure steps are fundamental to completion of the procedure. The problem is that that all the procedure steps can be completed, in the right order with the correct devices, but they can be completed badly. The steps score attained by the trainee will not however reflect the poor quality of their performance [33, 42]. Error metrics in contrast are an excellent measure of performance quality and show the greatest sensitivity to the measurement of performance quality across all medical domains. In the systematic review and meta-analysis the results across all of the prospective, randomized, and blinded clinical studies demonstrated a 60% reduction in objectively assessed performance errors [44]. If a trainee undertakes a training program with metric-based training to proficiency, errors during the learning curve can be minimized.

4.8 Why Is PBP Training so Effective?

Proficiency-based progression simulation training is effective because the requirements of the trainee are explicit. They know what steps to perform, in which order and with which devices. Furthermore, they also know what not to do, i.e. errors and critical errors. In an online didactic part training (prior to skills lab training), the trainees are given explicit instructions with videos and images demonstrating what they are required the do. There are also given explicit demonstrations of errors and critical errors. Rather than just viewing these materials the trainee is assessed on the material and given formative feedback as they progress through the module. The passing benchmark is based on the mean of the objectively scored performance of experienced surgeons taking the exact same test on the online module.

The didactic materials in the online module are derived from the procedure metrics which in turn were derived from very experienced practitioners. The aim of the online module is to teach the trainee about the optimal and suboptimal performance of the entire procedure. Some phases of the procedure may receive more attention than others. This is because some phases of the procedure were better discriminators of the objectively assessed performance of the novices and experienced surgeons in the construct validity study. These data indicate which part of the procedure the trainees find more difficult than other phases. This information should be used to guide the education and training curriculum. The function of the online education module is to ensure that the trainee arrives at the skills lab training course knowing what to do and what not to do. Furthermore, the trainee may not be consciously aware of the fact, but they *do* know the metrics and their operational definitions which in turn have been used to construct the proficiency benchmark. Thus, when the trainer gives the trainee metric-based formative and summative feedback on their performance the trainee understands precisely what the trainer is saying to them.

When the trainee arrives for training at the skills laboratory, the trainer has a very good idea of what the trainee knows and what they do not know. Furthermore, the variability in the knowledge levels between different trainees is quite low as all of them have had to pass the didactic model at a quantitatively defined performance benchmark, which is usually quite high, i.e. >80 or 90%. The trainee can take the assessments on the online module as many times as they like, but they must pass at the benchmark to successfully progress to skills laboratory training. So often in training progress is impeded by the weakest trainee as training invariably regresses to this level to make sure that the class of trainees' progress at a reasonably similar pace. The requirement to complete and pass the online model prior to training mitigates (but does not totally preclude) against the situation occurring.

In the skills laboratory, the trainee progresses through the simulation training, coached by faculty trained in the use of the metrics and how to score them. At Orsi Academy, we now insist that all faculty teaching on Orsi courses must have studied the metrics and have demonstrated that they can score them with other faculty to an inter-rater reliability >0.8. Knowing the metrics and being able to use them reliably is imperative to effective and efficient skills training. Furthermore, using the same metric-based template as the trainees ensures that communication about skill performance between faculty and trainee is objective, transparent, and fair. The trainee is required to engage in deliberate rather than repeated practice. Repeated practice as being the traditional approach to learning skills in surgery. This simply means that the training practices the skill over and over again possibly with feedback until the trainee or their supervisor think we are good enough. Deliberate practice [40] in contrast dictates that the trainee must perform units of the skilled performance in a specific manner. These performance characteristics are explicitly detailed in the procedure steps as are the errors associated with those performance units. So, for example, the phase of a procedure is made up of chains and sequences of performance units. This means that each performance unit has an explicit description (in the step) about how it should be performed. This description has been derived from the experienced surgeons in the initial procedure characterization. It has then been validated in a modified Delphi by a larger group of experienced surgeons. What was agreed in the modified Delphi is that the description of the step and associated errors may not be the only way to perform that particular step, *but it is not wrong*. Thus, the detailed information in the procedure step affords the trainer the ability to give the trainee explicit and constructive feedback on their performance during training. The trainee may not have been aware of what they did wrong or suboptimal during a particular step but the trainer will identify what they did wrong and explicitly guide them on how to do it correctly.

This approach means that the shared wisdom of optimal and suboptimal performance from the three surgeons in the original procedure characterization and the larger group of surgeons attending the modified Delphi is made available to the trainee throughout their training. Traditionally, trainees have observed the master surgeon performing a procedure or units of a procedure and inferred why they did things in a certain way. Sometimes the master surgeon would explain aspects of their performance. One of the problems with this relationship, however, is that the master surgeon often assumes trainee implicit knowledge which in fact does not exist. Proficiency-based progression training makes no such assumptions and gives the trainee explicit direction on what to do and what not to do. Furthermore, they are also given constructive formative feedback throughout training. This means that the trainee gets the constructive feedback proximate [63] to their performance error which means they are less likely to make the same error in future efforts.

4.9 Benefits of Formative Metrics

- Trainers can determine the performance level of trainees, specific to intraoperative steps and performance errors.
- Trainers can determine what modifications or changes in instruction are required to optimize training.
- Trainers can determine what procedures, at what time, trainees should be training on and at what level of independence they can operate at.
- Trainers can inform trainees about their progress and set agreed goals for improvement.
- Trainees are aware of their training progress and take responsibility for their own learning.

4.10 The Concept of a Pre-trained Novice

The trainee continues with their skills laboratory training until they have demonstrated the quantitatively defined performance benchmarks before progressing. This probably means a tiered approach to skills training. For example, at Orsi Academy, we first ensure that the trainee knows how to use the particular robot (basic device or technical training). Once they have mastered these skills they then progress to basic surgical skills training. Here they learn suturing and knot tying with the surgical robot, blunt and sharp dissection, and the correct and safe use of diathermy. Once they have acquired these skills to the metric-based benchmarks they will then progress to higher fidelity simulation models such as an anesthetized pig and eventually performing part or a full procedure on a cadaver. Each of the tasks that the trainee works on will have an associated set of metrics, with steps, errors, and critical errors. These task metrics will also have gone through the same validation process as surgical procedure metrics and have a quantitatively defined proficiency benchmark based on the performance of experienced and practicing surgeons. This approach affords the trainee the opportunity to build and hone their robotic surgical skills. It means that when they get to the point of performing a full procedure on a cadaver, they already have the repertoire of skills required to perform the procedure. They have however not chained and sequenced the skills in the order required to perform the full procedure. The function of the cadaveric model is to afford the trainee the opportunity to integrate and sequence their skills to perform the procedure in a safe environment with no risk to the patient. In the past, this integration and sequencing (even if it had been trained) would have taken place in the operating room on the first patients that the surgeon performed the procedure on.

The proficiency-based progression approach to training means that a trainee arriving in the operating room to perform a specific procedure for the first time is in fact a pre-trained novice [64]. They have acquired the skills to perform the procedure to quality assured and proficiency benchmarks and their performance levels have been verified. The trainee almost certainly has also performed the procedure on at least an animal model but most probably a cadaver. This means that they know what to do and what not to do, but they have never done it on a real patient. They will no doubt demonstrate some elements of a learning curve, but their rate of skill acquisition and performance safety will almost certainly be significantly better than that of a traditionally trained surgeon. This approach will almost certainly have significant and profound patient safety implications.

4.11 Team as Well as Individual Training

Over the last half-century, procedure-based medicine has become significantly more complex and technology-dependent. This means that patient outcomes are not simply dependent on the performance of the surgeon or interventionist. Good patient outcomes are fundamentally dependent on the operator and the team assistant and supporting them. It is universally accepted that team training and communication skills (TT&C) are imperative to efficient, effective, and safe operating. There is, however, a lack of consensus on how to best train and assess TT&C skills. There is also no or very few proficiency-based curricula or quantitatively defined proficiency benchmarks for these skills. Currently, TT&C skills seem to be taught as an educational experience and assessed with Likert-type scales rather than in the same clearly defined manner that operating/procedure skills are. One of the few exceptions is the work of Dr. Dorothy Breen at Cork University Hospital in Ireland.

Dr. Breen, a consultant intensive care specialist was concerned that the communication skills for the handover of a deteriorating patient were not as effective as perhaps they should have been. This was despite the fact that the Health Service Executive (the public health provider in Ireland) had a bespoke and mandatory training course for the learning of communication skills for the handover of a deteriorating patient. Furthermore, these mandatory courses were assessed, and a certificate given to trainees who passed the course.

In a prospective, randomized, and blinded clinical study [45] previously validated performance metrics of safe, effective, and efficient handover of a deteriorating patient were used for training and assessment. The metrics were used to establish a quantitively defined proficiency benchmark (for doctors and nurses). All the participants in the study had already taken and passed the mandatory training course 2 weeks prior to the start of the study. Individuals were randomly assigned to one of three groups. The first group were assessed on a simulated case on the handover of a deteriorating patient. This group had already undergone a nationally approved and mandated training course for these skills and thus gave a good indicator of the performance level of workers across the country. The second group as well as the national training had 3½ h of simulation training and performance feedback on their handover of a deteriorating patient. The third group had the exact same training as Group 2, with the exact same simulated cases but, the simulated cases had performance benchmarks for information about the case that should have been handed over. When the trainee had completed the handover of each simulated case, they were given feedback on the quality of the information in their handover, including omissions and inaccuracies. Training for this group was only complete when the trainees demonstrated the proficiency benchmark for the simulated cases, on two consecutive training trials.

At the end of training, all three groups were assessed in a high-fidelity simulation suite (on a novel simulated case) on their capacity to hand over the appropriate information on the deteriorating patient. Performance was assessed using the exact same criteria as had been used during training.

The results show that only 7% of trainees from the national and mandated training program demonstrated the proficiency benchmark. The group which had simulation training as well as the national training program did only marginally better, i.e. 13% demonstrated the proficiency benchmark. 60% of the proficiency-based progression training group demonstrated the proficiency benchmark. The results of the study are important for our number of reasons. The first is that they seem to have replicated the findings of Angelo et al. [30]. Uncomfortable as it may be, the results indicate that conventional training programs are ineffective. The conventional training program in the Angelo et al. study was a requirement of the Arthroscopic Association of North America; the training program in the Breen et al. [45] study was implemented on behalf of the Irish National Health Service Executive. Furthermore, the course was mandatory for all health care workers in Ireland. The results from the Breen et al. study verify that having simulation training on a course does not in itself impact on the effectiveness of training. There is only one way to know what someone has learned on a skills training course and this is to assess their performance on completion of the course. Proficiency-based progression simulation training goes one step further than this and directs that training is not complete until the proficiency benchmark has been demonstrated. Using this approach to training will without doubt have profound implications for the administration of training in a healthcare environment. However, this approach to training will almost certainly also have profound implications for patient safety, morbidity, and mortality.

The results of the Breen et al. study demonstrate that communication skills are amenable to the proficiency-based progression methodology and performance improvement is of the magnitude observed for surgical procedure skills. These results also show that the training must be more than an interesting educational experience. Perhaps aside from this issue, the study also demonstrated that communication skills need adequate time to be learned. In a pilot study, Breen and her colleagues were given insufficient time to train the skills and the consequence was very low proficiency demonstration levels.

Team training is certainly more complex than the handover of information from one individual to another. The skills, however, for the team task are amenable to the same performance characteristics as would be used for surgical procedure. The metrics developed from this exercise will also need to go through the same validation process and the development of proficiency benchmarking probably for individuals within the team as well as the overall team.

4.12 Conclusion

Proficiency-based progression is a very effective approach to the learning and quality assurance of performance levels at the end of training. This approach is derived from a metric-based understanding of what optimal and suboptimal performance is. These performance metrics are then subjected to a rigorous validation process and proficiency benchmarks are quantitatively defined on the basis of the objectively assessed performance of experienced practitioners. Simulations are used as training tools for the delivery of metric-based formative and summative feedback to trainees. Training is only complete when the trainee demonstrates the quantitatively defined proficiency benchmark. Across surgical and medical specialties this approach to training has been demonstrated to be highly effective. Small-scale evidence exists demonstrating that this approach is equally effective in the training of communication skills. This approach to training may be administratively more cumbersome, but it is scientifically more rigorous, and quality ensures what the trainee (no matter how senior) can do on completion of training. It almost certainly represents a paradigm shift in how doctors are trained.

Key Points

- Simulation-based training meets the need to move training out of the operating room.
- Starting with a systematic approach, characterization by a procedure expert's metrics are identified, operationally defined and then validated. The metrics are then used to quantitatively defined performance benchmarks (i.e., proficiency level) based on the objectively assessed performance of very experienced surgeons.

- Training is not complete until the trainee has demonstrated the proficiency benchmark.
- On average, performance errors, which are the best discriminator of performance quality are reduced by ~60% when applying the PBP simulation training. *This does impact on clinical outcomes.*
- Prospective, randomized, and blinded clinical studies show that PBP shortens the learning curve.
- PBP is a scientific method of training that uses simulation as a tool for the delivery of metric-based training to proficiency.
- PBP simulation training does not preclude the art of surgery, but it does quality assure the performance of the trainee before they operate on their first patient.
- Objective, transparent, fair, validated, and implementable metrics for the objective assessment of performance is imperative to ensure that the simulation training is more than an interesting educational experience.

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Chapter 5
The Importance of e-learning

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5.1 Introduction

5.1.1 Brief History of e-learning

Almost three billion people worldwide use the Internet every day. The spread of the World Wide Web has enabled people to interact and exchange knowledge more effectively than is possible with traditional non-online methods [1]. Today's trainees have the

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opportunity to access information and training platform via e-learning [2]. e-learning is defined as the provision of educational content through an electronic system [3]. e-learning tools range from online books to online curricula with varying degrees of user participation. In general, any platform available on the web, whose content, sequence, and rhythm are controlled by the learner, can be defined as an e-learning platform. e-learning offers unrivaled access to information, regardless of location, time constraints, or cost [4]. The history of e-learning is marked by several milestones spanning two centuries. The idea of providing educational content at a distance can be traced back to 1728 when Caleb Philips, a Boston stenographer, started a true distance learning course by sending educational content by mail [5]. More than a century after this pioneer's idea, in 1858, the University of London was the first university in the world to offer entire courses by correspondence, through the creation of the so-called External Program [6]. However, the term "distance learning" was not forged until 1892 and was first used in a pamphlet by Wisconsin-Madison; the same university began to create the conditions for e-learning in 1902 by sending its students lectures on phonograph records [7]. In 1922, Pennsylvania State University revolutionized distance learning by broadcasting entire courses over the radio, increasing the speed and efficiency of the content delivery [8]. As television grew in popularity, Iowa State University introduced WOI-TV in 1950, the first television station to broadcast university courses [8]. In 1969, the first university based entirely on distance learning, the Open University, was founded in London; the inauguration of this university met with several criticisms from public opinion, still attached to traditional learning environments [9]. The first steps in the development of online-based education were taken in 1960 when the University of Illinois established Programmed Logic for Automated Teaching Operations (PLATO), the first intranet system through which students could access recorded materials and lectures. e-learning was indeed born; however, the term was first used in 1999 [10]. More than 14 years after the development of PLATO, in 1974, Ceft and Kahn published ARPANET [11], the precursor of the Internet, for the public. At the beginning of its history, access to ARPANET was limited to the educational system for internal communication and data exchange. In 1981, Western Behavioral Sciences Institute became a pioneer in the field of e-learning, creating the first online college program that offered pre-recorded lectures to students. The game-changing development took place in 1991, more than 30 years after the first version of ARPANET, when the World Wide Web was released to the public and guaranteed access to the Internet for all citizens. With the growing popularity of the Internet, Computer Assisted Learning Center (CALC) introduced CALCampus, the first synchronous online university courses with real-time teaching and participation in 1994 [12]. Finally, in 1997, Blackboard™, the first platform for the creation and distribution of online teaching materials and online courses, was released. Only in 2001 did medicine begin to use e-learning as an appropriate tool, with the inclusion of an e-learning component in the Surgical Education and Training Program (STEP) by the Royal College of Surgeons of England [13]. Since the development of PLATO, the focus of educational technology and e-learning has evolved and changed. In the beginning, the main objective of these platforms was programming, and the learning process was mainly oriented toward a behavioralist, passive learning approach. Today's e-learning has become more flexible and interactive, based on a modern constructivist and cognitivist approach [14].

5.1.2 e-learning Platforms in Surgical Training

The first steps of universities in e-learning consisted mainly in uploading lecture notes and slides to websites. According to current definitions, this would be considered as resource allocation rather than e-learning itself. Today, e-learning is characterized by virtual learning environments (VLE) in which all aspects of the course are managed via a standard interface [15].

In recent years, e-learning has become so widespread in medical courses that current trainees are already experienced users. Although they are highly skilled in the use of e-learning platforms, trainees usually emerge from a broad curriculum that provides little basic practical knowledge [16]. Since the introduction of the European Working Time Directive (EWTD) in hospital environments, residents have significantly reduced contact time with both trainers and peers and experiential exposure [17]. As a result, skill training courses and simulations have become indispensable. e-learning courses are accessible independent of time and location and can better fit into the schedules of surgical trainees, who mainly work at shift rotations; moreover, many surveys show that knowledge acquisition for medical trainees mostly occurs off duty, outside of the workplace [18]. Furthermore, e-learning platforms encompass a variety of learning styles and effectively provide a wide range of surgically relevant information. Interactive, web-based media have been shown to improve surgical skills and reduce error rates and operative time [19]. In addition, the use of case-based e-learning software has significantly improved the retention of the theoretical knowledge [20]. These factors have been an important driver for the development of several surgical e-learning platforms. Several institutions, such as the Royal College of Surgeons of England, Ireland, Scotland, and Australia, have already included e-learning content in their residency program [21]. In 2018, Turkey launched the E- Learning Residency Training Program (ERTP), a national pilot study with the creation of an e-learning platform for the standardized training of residents in urology [22]. A recent systematic literature review, after analyzing 87 studies on Internet and software-based platforms, showed that most e-learning platforms are effective teaching tools, but that access to these VLEs is often limited or the costs are prohibitive [23]. Current students and trainees have been referred to as the "YouTube generation" due to the increasing use of YouTube as a source of learning [24]. Several studies have assessed the quality of uploaded videos and found that despite the high quality of some of the videos updated, an objective parameter to predict the educational quality of uploaded content is lacking. As a result, there is a need for easily accessible VLEs that are able to offer free, quality-checked content [25]. Several websites provide access to surgical data via Internet platforms; the following websites offer information on urological surgery:

- Urosource (https://urosource.uroweb.org)
- WebSurg (https://www.websurg.com)
- M*e*dscape (https://www.medscape.com)
- MEDtube (https://medtube.net)
- Surgery in motion (https://surgeryinmotion-school.org)

- Royal College of Surgeons in Ireland (RCSI) (http://www.msurgery.ie)
- Humber School of Surgery YouTube Channel (https://www.youtube.com/channel/UCFQzDQMy9Gi8iZZlU_Cc7Kg)

5.2 Advantages of e-learning

5.2.1 Information Delivery

Medical education has undergone enormous changes in recent years, moving from traditional teacher-centered learning to a student-centered model [26].

The benefits of online e-learning focus mainly on the operational and logistical advantages that asynchronous learning can offer [27]. Online e-learning can be conducted and enjoyed on a variety of platforms, with increasing attention being paid to mobile accessible content, opening the way for ubiquitous learning (U-Learning) [28]. Other features of e-learning that can improve the quality of learning are granularity, i.e., the ability to segment contents to facilitate their assimilation and allow flexible planning of learning, interactivity to maintain a consistently high level of attention, and finally, personalization of the learning experience, allowing participants to create their own learning plan [29]. e-learning can take many different forms that can be adapted to the needs of specific learning environments and learners, such as web-based data resources, online interactive modules, virtual reality environments, and virtual patients. These resources are often brought together and linked as part of an online learning platform. Medical trainees generally benefit from the flexibility of e-learning in terms of location, time, and pace of learning [30], but also has disadvantages such as social isolation [31], loss of concentration [32], technical problems, and poor instructional design [30]. Recent evidence suggests that the use of e-learning materials helps students to save time in acquiring new information and to perform better in active learning-related tasks without significantly increasing the time spent on courses [33]. A recent systematic review analyzed training strategies for teaching evidence-based practice to undergraduate health students and found that the use of technology to support learning and training appears to be the best suited for future health professionals [34]. The development of interactive, updated, openly accessible and specific modules for surgical trainees provides the user with access to important information for the development of an effective skills set [35].

Indeed, surgical trainees require the development of knowledge, technical and non-technical skills, and e-learning can be a fundamental tool for their development.

Some guiding principles have emerged for the development of the e-learning content [21]:

- e-content must add value to existing resources rather than duplicating them
- e-learning should combine e-resources with conventional materials to accommodate different learning styles

– Community discussions should be created to encourage teacher input and peer contact
– Online formative assessment provides a safe means of self-evaluation
– Personalization helps learners to achieve agreed objectives

5.2.2 e-learning and Human Memory

Learning and memory are complex functions that depend on various levels of cognitive structures [36]. Memory can be divided into sensory, short-term and long-term memory as well as declarative and non-declarative memory. Sensory memory is a buffer for stimuli perceived through senses. These images are retained only for a brief moment, typically less than half a second; beyond the 0.5 s mark, every memory is moved to short-term memory. Short-term memory consists of the conscious maintenance of a particular sensory stimulus for a short period of time, typically a few minutes, after which it is no longer present; short-term memory has low capacity, as the information being held there will quickly be dismissed or moved into long-term memory. The concept of short-term memory has been revolutionized by Baddeley with the introduction of working memory [37]. According to Baddeley, short-term memory is more than just a passive recipient of information, rather is composed of four components: the phonological loop, whose role is to deal with auditory information, the visuo-spatial sketchpad, a store that holds visual information for manipulation, the episodic buffer, a passive system devoted to connecting information across dominions to form integrated memories from visual, spatial, and verbal information according to the time they take place, and the central executive, responsible for the regulation of cognitive processes and integration between working memory and long-term memory. Long-term memory is defined as those acquired memories that are stabilized and strengthened over time and become resistant to interference. To enable the creation of long-term memories, a particular experience must go through three steps: encoding, consolidation, and retrieval; each time a memory is retrieved, it goes through a phase of reconsolidation, which allows neuroplasticity to create a long-term memory. The long-term memory can be divided into declarative and non-declarative: Declarative memory is commonly described as the "conscious" memory and is divided into semantic declarative memory, which contains all the information obtained through study or observation, such as clinical signs of renal colic, the anatomy of the pelvis, the physiology of micturition, and episodic declarative memory, which stores the information associated with the subject's personal experience; the two types of declarative memory are closely related: episodic memory seems to be able to attach an emotional value to semantic memories, making them easier to retrieve. Non-declarative memory, also called procedural memory, includes all our skills, our habits, the way we do certain things, all those actions that are automated after an initial training phase: driving a car, riding a bicycle, avoiding an obstacle [38]. Skills used by surgeons during surgical procedures are based on information stored in both long-term memories.

According to the model of Fitts and Posner [39], learning a new skill involves three phases:

- the Cognitive phase in which the learner develops an understanding of the sequence of events that occur in the construction of a skilled performance.
- the Associative phase, in which the learner practices until efficient performance patterns emerge, ineffective features are dropped, and performance begins to automate; in this phase chunks of activity are combined into smoothly executed actions; the learner begins to perform more than one task at a time, resulting in better dual-task performance. This phase has the greatest importance in surgery, considering that surgical procedures require several cognitive demands, especially attentional resources; by increasing the number of automated skills, more attentional resources remain available for higher-level tasks, such as intraoperative problem solving; at the end of the first two phases, the learner "knows the procedure."
- the Autonomous Phase, in which the learner perfects his/her skills through practice, leading to an automatic, unconscious, instinctive execution of the planned action; at the end of this phase the learner "knows how to do the procedure."

Phases 1 and 2 are characterized by relying on declarative knowledge forms and rules to complete the task, while in phase 3 learners can complete the task even in the presence of disturbing factors by prioritizing and sequencing events in the event of unplanned events and applying the acquired skills without being aware of their execution. A known disadvantage of reaching phase 3 is that the declarative knowledge regarding a particular skill is often lost to the practitioner. This leads to a skilled practitioner but lousy trainer. Another problem associated with skill automation is the acquisition of bad habits during training, especially in the case of poorly designed or poorly monitored simulations.

Cognitive psychologists have developed various techniques to help people remember learned information. Many of the aforementioned techniques are based on Miller's theory of "chunking." This theory is based on the idea that the human mind can elaborate a certain amount of information, estimated as 7 ± 2 chunks; considering this, the ability to chunk information in organized sets becomes fundamental when developing e-learning contents. The surgical procedure itself lends itself to the process of "chunking," e.g. preoperative preparation, the procedure itself, and the postoperative management [40]. Another important aspect that has been pointed out earlier is that episodic memories are usually better remembered than semantic memories; therefore, linking new information to what they already know can help learners to acquire new skills faster and more efficiently. Visualization is a useful tool for improving memory: PowerPoint presentations, movies, and graphical representations of information are easier to recall to memory because they are able to summarize, prioritize, and stimulate learners' interest. Videos are particularly useful because they are able to show the order, sequence, and context in which the events occur. As such they are very powerful tools that help learners to remember complex information [41].

The frequency of repetition or rote learning is another key element in retaining information and linking new concepts to skills already learned. As early as 1880, the psychologist Hermann Ebbinghaus carried out some research on memory and developed the so-called forgetting curve; according to his and further research, up to 50% of newly learned information is forgotten within 20 min from the end of the lecture and up to 75% within 30 days if the information is not recollected [42]. In 2018, MacLeod et al. analyzed the role of memory reactivation and demonstrated how it can induce neuroplasticity and better storage of newly acquired information [43].

According to Friedman, learners can be divided into three main types: visual, auditory, and kinesthetic learners. Visual learners learn mainly through visualization; auditory learners prefer oral explanations to written form, while kinesthetic learners learn to solve real-life problems. The awareness of these different types of learners leads to a wide variety of teaching strategies [44]. The implications for these findings are obvious and support the use of e-learning platforms. e-learning can stimulate multiple visual and auditory pathways of the human mind; can use simulations to help kinesthetic learners better retain new information; can expose learners to multisensory experiences that significantly increase the level of recall of newly developed information. Through easily accessible platforms, lectures can be experienced how often learners wish to be presented, despite location and time schedules. e-learning can also improve the understanding of events with complex temporal and spatial relationships, such as surgeries, making it a powerful tool for surgical trainees [45].

5.2.3 Lecture's Structure: The Importance of Organization and Structure

The structure of e-lectures is of utmost importance to create effective experiences and improve the quality of learning. To develop a good curriculum, e-content should focus on:

- relevant knowledge (i.e., anatomy, pathology, physiology)
- steps of the focused tasks
- definition and illustration of the most common mistakes
- examination of all previous information to ensure that students understand the cognitive component of skills before moving on to technical skills

However, it is not enough to follow a template. Many other factors must be taken into account when organizing a lecture. As previously stated, according to Ebbinghaus studies, memory retention decreases over time, with over 50% of newly learned material being forgotten within 20 min and up to 75% in a month if this information is not revised. Reintroducing the lessons in smaller increments will help participants to retain their knowledge over a longer period of time [46].

e-learning can help participants to learn at their own pace, even allowing them to pause, resume, and move between lessons. This ability allows participants to increase information retention by revising completed modules in shorter bursts. Dividing the aforementioned information into smaller, shorter lessons allows students to focus on one piece of information at a time and guide them toward a specific learning goal. Trainers should also consider the Primacy and Recency Effects when evaluating how to order items on a list and when there is a need to focus on specific items on the list. Our brains tend to remember the first and last items more easily. These abilities are called Primacy and Recency effect, respectively. In the case of the primacy effect, theories suggest that items presented early on the list are easier to recall because our brains have more time to process and more opportunities to retrieve this information from the moment of first contact [47]. As for the Recency Effect, items presented in the latter part of the series are more easily recalled. Without repetition, memorized material cannot be transferred to the long-term storage and is therefore lost. Educators or administrators can use the Primacy and Recency Effects, showing the most relevant data at the beginning and end of the information to be learned, to maximize memory. Lectures should be created according to the principles of micro-learning, i.e., they should be short and set smaller and more specific learning goals. Shorter lectures reduce mental fatigue, also known as central fatigue, allowing students to acquire the key contents and take a break. This structure helps the brain to organize and process new information and then transfer it from short-term to long-term memory. Mental fatigue causes a decline in all areas of the cognitive spectrum such as planning, inhibition, and attention (executive, sustained, goal-directed, alternating, divided and conflict-controlling selective attention) [48, 49]. This impairment is related to neurotransmitter depletion, which causes neurons to fail in transmitting impulses and leads to temporary synaptic depression [50], preventing neuroplasticity. Shorter lectures, namely less than 15 min, can prevent central fatigue by maintaining an adequate level of cognitive task performance and, in combination with interactive, focused content, capture learners' attention, enabling them to perform better and complete the e-learning component of the curriculum more quickly [51, 52].

5.2.4 Effective Content Delivery

Creating an e-learning environment for surgery is a complex task. It requires a comprehensive knowledge of the latest pedagogical principles and requires a good measure of creativity. The development of new technologies allows teachers to create highly interactive and immersive e-learning experiences by using interactive virtual models, simulation platforms, or real case scenarios. In the latter case, learners are confronted with interactive clinical and surgical environments and receive live feedback on the decisions and actions they make without any impact on real life. This safe environment allows and welcomes mistakes to be made as a trainee experiments and develops understanding and skills. By evaluating the progress of trainees and providing real evidence that trainees have completed a required module before attending real-life training, face-to-face training ensures that a baseline, benchmarked level is achieved and improves the quality of time spent on costly lab training.

e-learning environments are as effective as their instructional design. According to Merrill et al., despite their preferred learning strategy, adult learners tend to perform better when new information are proposed through real-life situations, when it is linked and integrated with prior knowledge, when they are challenged through in-lecture polls and discussions, and when they are asked to apply the newly acquired knowledge [53]. According to Harden, the four main strategies for developing an effective e-learning resource are based on the acronym FAIR:

- Feedback to the students
- Active engagement of the students
- Individualized teaching that recognizes different learning needs and styles
- Relevance of the content to enable the theory to be applied in practice [54]

In accordance with the teaching principles of higher education, which have been developed exclusively for a pedagogy based on e-learning, the design of e-learning content should be based on the following five principles:

- individually tailored to the student
- integration of the content into the student's experience
- interactivity between students and teachers
- immediate feedback
- interactive approaches to reinforce learning [31]

Curricular content should be easy to read and understand and avoid colloquial language, especially when trainees are attending courses in their second language. According to Harden, teachers who develop e-learning materials should always pay attention to the ABC:

- Appropriateness for the audience, arguments that will influence the reader
- Brevity, balance of description, background of the content provided
- Comprehensiveness, clarity, coordination between information and visual presentation [54]

Salmon, one of the most relevant experts on the application of e-learning in higher education, described a five-level model, in which the learning stages are scaffolded and each level takes students to a higher level of autonomy, gradually moving from moderator-led learning to a constructivist, individualistic approach [55].

According to Ruggeri, in order to develop an effective e-learning curriculum, both teachers and trainees need some specific characteristics: a positive disposition toward e-learning, technological skills, and the right motivation to develop and use e-contents [56]. Such an attitude is common among medical students and residents: Feedback collected from surgical residents in the UK showed a high level of dissatisfaction with traditional learning models, while the introduction of new technologies into the learning path was enthusiastically welcomed.

5.2.5 Performance Assessment

During the development of e-content, teachers should always assess learners' understanding and progress as they work through the eLearning curriculum. This assessment is of the utmost importance to evaluate students' performance and ensure that trainees develop their skills and knowledge to at least a minimum acceptable level before moving on to more challenging parts of the package. Without a thorough assessment of knowledge before the student can progress, the following parts of the learning will become increasingly difficult for the student, increasing the risk of major misunderstandings of the material learned. It is imperative to avoid this chain of misunderstandings and mistakes that could lead to dramatic consequences for future patients. As already mentioned, bad habits are really easy to acquire and difficult to eradicate, especially once these have become part of the general practice of the individual doctor. In 1967, Scriven described the concept of "formative" assessment. According to his definition, "formative assessment" is part of the training pathway and scoring a certain performance rather than grading it, are seen by the trainees as non-threatening [57]. This approach allows these assessments to improve learning rather than hinder it, allows trainees to assess their progress, and improves retention by "effortlessly" retrieving newly learned information, facilitating the creation of long-term memories through neuroplasticity, and allowing for faster retrieval of the information needed in future situations. They are also of great value to trainers as they provide them with information on the progress of trainees and highlight possible errors in the proposed e-content, such as poor explanations, lack of important information, or superfluous material. Assessments should start as soon as the e-contents are made available and the main concepts are taught and should be planned to cover the whole period of e-learning [58]. Another important task of assessment should be to serve as a mandatory step before accessing to skill laboratories. One of the main problems of skills laboratories, which are usually quite busy and scarcely available, is that the level of skills taught in a particular course is tied to the level of the trainee with the lowest level of preparation. e-learning and the correct use of assessment could be the main tool to raise the level of the trainees to a level where minimal time is wasted teaching unprepared trainee's theoretical concepts they should already possess. Students who wish to participate in practical skill training need not only to study the provided e-content, but also to reach a certain level in pre-practical assessment. This practical approach guarantees an appropriate minimum level of knowledge to ensure that time in the skills lab is used efficiently. Lastly, performance assessment can be used to identify gaps in students' knowledge, in order to fill them before the end of the course.

5.3 Optimization of e-learning for a PBP Methodology

The courses contents should be developed starting from quality-verified materials. e-contents should be developed according to an instructional design which ensures that the trainers have the capacity to collect and analyze information about trainees' performances and scores. Furthermore, e-learning should be structured according to methodologies that have already been proven effective for information and skill transfer from trainer to trainees, such as proficiency-based progression (PBP) training [59]. PBP has been successfully applied in the development of several technical skills [60, 61] and, recently, has been used as a base for the construction of robot-assisted surgery's curriculum [62]. According to PBP methodology, a specific procedure or skill is subdivided into several phases. All phases are then divided into discrete procedure steps. For each step, errors and critical errors are identified. All of the steps are performed in a specific sequence identified by a panel of very experienced surgeons. Subsequently, these detailed metrics are vetted with the use of a Modified Delphi panel [63]. The Delphi Consensus approved metrics constitute the body of knowledge that the trainee must acquire before proceeding to practical training. Each lecture should contain a combination of text, videos, and presentation on each step, explaining and showing both error and critical error and successful completion of the step according to the metrics, other than the metrics itself. Presenting learners, a structured video, showing the order, sequence, and context in which, the events occur will help them to acquire complex information easily. At the end of the theoretical part of the course, students should be assessed through an interactive questionnaire regarding the covered topics. The score obtained at the end of this test must be high enough to reach the pre-set benchmarks. Benchmarks, according to PBP methodology, are based on the average performance of the experienced surgeons who have completed the same assessment. Thus, at the end of the process, trainees must demonstrate a theoretical knowledge comparable with experts before proceeding to the training part of the program.

The aforementioned assessment allows the trainer to acquire data about trainees' involvement, such as the number of times a certain student has reviewed a video or how many times has failed to reach the benchmarked score during assessments. This could provide trainers important data on the quality and appropriateness of the provided contents, but also information on which aspect a certain trainee has to improve before reattempting the assessment.

5.4 Future Directions

e-learning approaches are becoming more and more popular with the passing of time and evolving of technologies. The function of these technologies should be to enhance and support traditional education and training activities. It is of utmost importance to avoid thinking of virtual and online learning strategies as an effective stand-alone approach to prepare trainees for clinical practice [64]. All medical practice, indeed, require the use of learning a technical skill that cannot be acquired with e-learning on its own. eLearning should be used to give trainees the knowledge to better approach practical skills training, serving as an adjunct to improve the effectiveness of a curriculum, especially in the case of curricula with a main cognitive component that can easily be presented as e-modules. These sections should ideally be accompanied by simulation-based training to develop a full variety of surgical skills, resulting in successful training curricula [65]. Despite the lack of high-level evidence, experiences from previous studies suggest that PBP implementation could improve e-learning performances. Nowadays, no evidence about the efficacy of eLearning on its own to prepare individuals to perform basic surgical tasks are available. Further studies with a high level of evidence are needed.

Key Points

- e-learning can take many different forms, adapting to the needs of learners.
- e-learning can stimulate multiple visual and auditory pathways of the human mind, helping different kinds of learners to better retain information and improving the understanding of complex temporal and spatial sequences (like surgical procedures).
- e-learning allows trainees to learn at their own pace, helping students to increase information retention.
- e-learning lectures should last less than 15 min in order to maintain an adequate level of the cognitive task.
- In order to effectively deliver e-contents, information should be proposed through real-life situations, should be integrated with prior knowledge, and tested right after the lecture.
- e-learning programs should be structured according to a verified methodology such as PBP. At the end of the e-learning process, trainees should demonstrate theoretical knowledge comparable with experts before proceeding to the training part of the program.

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Chapter 6
Proficiency and Competency Assessment in Surgical Training

Ian Eardley

6.1 Introduction

The traditional model of surgical training was an apprenticeship. The system of apprenticeship first developed in the later Middle Ages and came to be overseen by craft guilds and town governments. A master craftsman employed young people as an inexpensive form of labor in exchange for providing food, lodging, and formal training in the craft. A modification of this historical system was the basis of surgical training for many years and involved a surgical trainee learning initially by observation, followed by a gradual introduction to surgical techniques, initially with careful and close supervision, but latterly with "detached" supervision, perhaps from the theater coffee room. Feedback from the trainer was often intermittent and informal, and the model required and usually achieved extensive operative experience. Apprenticeship based training was therefore suited to a healthcare system where extensive operative experience was available, and in such circumstances, the eventual outcome was usually satisfactory. However, such training was prolonged and often required repeated exposure to a large number of procedures before the trainee became competent to undertake the procedure independently. There was also, inevitably, a potential for the increased risk of complications along the way, especially if the level of supervision was imperfect.

Such a method of learning was never going to be sustainable and there have been a number of drivers for change. The first has been the reduced clinical exposure for surgical trainees that has arisen as a consequence of reductions in working time and increased trainee numbers. A second driver for change has been the increasing need for accountability as a consequence of patient expectations and the requirements of patient safety. A third driver has been a change in educational theory, with the

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recognition that assessment drives learning [1], combined with an acceptance that the traditional methods had poor validity and reliability. A final driver for change in many countries, but notably in Canada and the United Kingdom, has been regulatory, in that there has been a change in emphasis from traditional time-based curricula to competency-based curricula. As a consequence of this latter, the current surgical curricula in the United Kingdom have 7–8 "indicative" years of training with regular assessments along the way. Theoretically at least, trainees can progress through training at different speeds depending upon their ability, their aptitude, and their exposure.

6.2 The Meaning of Words

A variety of words have been used to describe surgical skill and performance. Words such as aptitude, ability, competency, proficiency, mastery, expertise, and experience are all words that can be used to describe the performance of the surgeon. The difficulty is that many of these words do not have precise definitions and as such, these words sometimes mean different things to different people. For instance, a recent systematic review concluded that there needed to be a clearer definition of what is meant by the term competence when it is applied to surgical performance [2]. For the purposes of this article, the meaning adopted by the UK medical training system will be used, namely that "competence" equates to the minimum skill required to safely and independently practice.

One of the earliest models of skill acquisition was the Dreyfus model. Stuart and Hubert Dreyfus proposed a model that described how learners acquire skills through instruction and training and described five stages of skill acquisition [3, 4]. Although the model was written while they worked within the United States Air Force Office for Scientific Research and is primarily focused upon the development of the ability to fly a plane and even though there have been a variety of academic criticisms, many of the propositions that they made have struck a chord within the surgical community [5]. Using their model, surgical trainees can be described as beginning their training as a "*novice*" and with learning, supervision, and instruction will progress through the stage of being an "*advanced beginner*" to becoming "*competent*." Within the United Kingdom, surgical training system competency is the lowest acceptable level of performance for certification and independent practice but the Dreyfus model demonstrates that this is not at the end of the line in terms of skill acquisition. With further experience, training and supervision of the higher levels of "*proficiency*" and "*expert*" are possible. In some versions of the model a sixth level, "*mastery*" is included. One way in which this terminology has been expanded to describe the characteristics of a surgical trainee is shown in Table 6.1.

A visual image of the progression of a trainee demonstrates the relationship between skill levels and experience (Fig. 6.1). As the trainee gains more experience, then with appropriate feedback, instruction, and learning, their performance levels

Table 6.1 The principles of the Dreyfus five-stage model of skill acquisition applied to surgical skill acquisition (adapted from [5])

Stage	Standard of work	Autonomy	Dealing with complexity	Perception of context
Novice	Unsatisfactory unless closely supervised	Rule driven, needs close supervision	Unable to cope with complexity	Tends to see actions in isolation
Advanced beginner	Straightforward tasks satisfactory with supervision	Uses rules to decide what is relevant, supervision needed for overall task	Appreciates complex situations but only able to partially resolve complex situations	Sees actions as a series of steps
Competent	Satisfactory, though may lack refinement	Able to achieve most tasks using own judgment	Copes with complex situations through deliberate analysis and planning	Sees actions at least partly in terms of long-term goals
Proficient	Fully acceptable standard routinely achieved	Able to assume full responsibility for own work and that of others	Deals with complex situations holistically, decision-making more confident	Sees overall “picture” and how individual actions fit within it
Expert	Excellence achieved with relative ease	Able to take responsibly for going beyond existing standards and creating own interpretation	Holistic grasp of complex situations, moves between intuitive and analytical approaches with ease	Sees overall “picture” and alternative approaches; envisions what may be possible

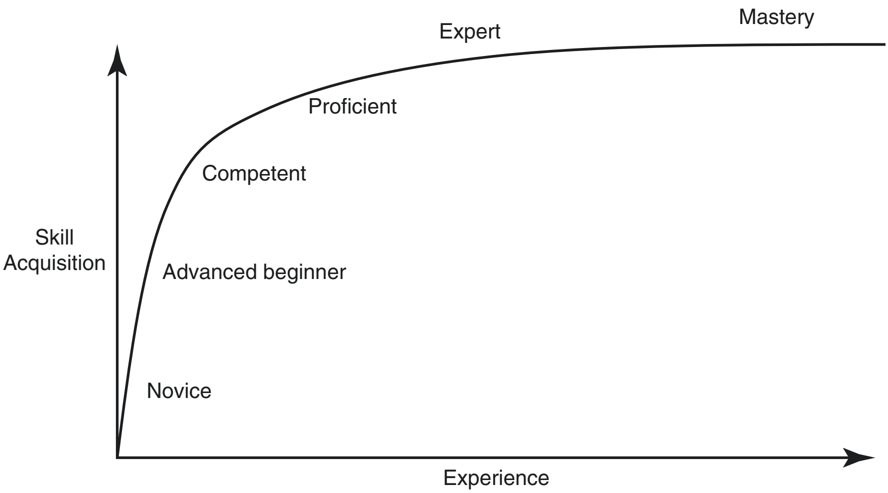

Fig. 6.1 A visual model of skill acquisition highlighting the relationship between experience and skill levels [2, 3]

will improve. Increasingly we are recognizing that not only does surgical experience facilitate skill acquisition, but that simulation can also be used at any point along this curve.

6.3 Assessment of Competence

In 1990, George Miller proposed a pyramidal framework for the assessment of clinical competence (Fig. 6.2) [6]. At the lowest level of the pyramid is knowledge (knows) followed by competence (knows how), performance (shows how), and action (does). This model has been the basis for the methodology that is currently used to assess clinical competence. At the lowest level, knowledge is usually assessed by some form of knowledge test such as multiple-choice assessments. Other tests such as simulation tests and Objective Structured Clinical Examinations (OSCEs) target higher levels of the pyramid. The challenge is to devise reliable and valid methods of targeting the upper levels of the pyramid.

In theory, at least there are a number of ways in which these higher levels of performance of a surgeon can be measured. Firstly, the outcomes of surgical treatment are a potential way of assessing the performance of a surgeon [7]. In practice, however, there are a number of problems with this approach. Firstly, in modern healthcare, the outcome of a patient is typically dependent upon the performance of a team rather than of an individual. Measurement of outcome therefore might not always accurately reflect the performance of the surgeon. Secondly, the existence of comorbidities can enormously affect the outcome for the patient and this variability in case-mix makes comparisons between different surgeons difficult. Finally, the

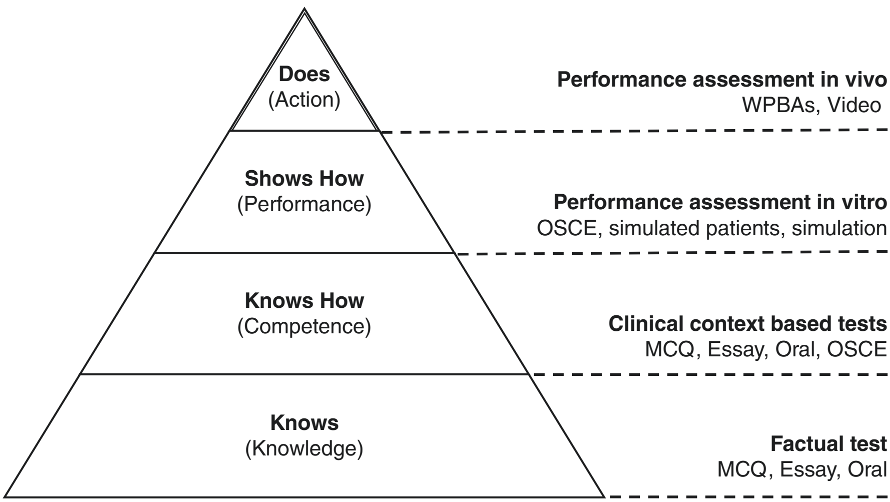

Fig. 6.2 Miller's model of performance and its assessment [6]

volume of cases that would need to be assessed in order to assess such outcomes is considerable and likely impractical as a means of assessing the trainee surgeon.

Traditional data sources for the assessment of competence can include clinical patient records, administrative databases, and logbooks but all these approaches have their own disadvantages. Review of clinical records is still sometimes undertaken (at least in the United Kingdom), for instance, when the performance of a surgeon is under question by the regulator or employer, but it is time-consuming and expensive and multiple records need to be reviewed for any sensible judgment to be possible. Databases and registries can provide information for the reporting of surgical performance, and the use of such registries has recently been introduced for some surgeons in the United Kingdom to describe summaries of caseload and morbidity. While the early registries were self-completed by the operating surgeon (with all the associated potential for bias) [8] more recent versions have been based around administrative databases and are currently intended to support self-reflection, appraisal, and learning [9]. Finally, surgeons themselves often keep logbooks of their cases, but while they provide excellent measures of volume, they are less useful for the assessment of process and outcome.

In theory, observation of a surgeon at work might be expected to provide the most accurate assessment of their performance, but there is the obvious worry that the presence of an observer might alter the surgeon's behavior. Accordingly, observation should perhaps either be almost routine or alternatively covert for it to accurately represent the performance of the doctor. It is with this background that the so-called workplace-based assessments (WPBAs) have been developed to assess the performance of a surgeon. For this approach to be effective there are several requirements;

- The observer should have the clinical expertise to be able to make appropriate judgments. So, for a surgical trainee, it is important that a surgeon is an observer making the assessment of technical competence. In contrast, it could be argued the most important observer of communication skills would be a patient.
- It is helpful to have both multiple observers and multiple observations when assessing the competence of the trainee since this will increase the reliability of the judgment.
- It is important that the observer is trained to undertake the assessment appropriately, and additionally to be able to provide appropriate feedback which will facilitate future learning.

6.3.1 Assessment of Competence in Surgeons

In most modern competency-based training systems, WPBAs have become the mainstay of competence assessment. By designing tools that are valid and reliable, a number of aspects of a surgeon's performance can be assessed. These assessments have a dual purpose; firstly, as a formative tool, to facilitate feedback for the trainee, with good evidence that regular, comprehensive, and well-structured feedback will facilitate learning and enhance the progression of the trainee [1, 10]. However, a second potential role is in the summative assessment of surgical trainees and while individual workplace-based assessments are rarely used in this way, a basket of WPBAs for a trainee, over a period of time, is a good indicator of whether that trainee is progressing appropriately.

There are a number of separate components of a surgeon's performance that can be assessed. Firstly, and most obviously there is the technical competence of the surgeon but given that most surgeons spend only a proportion of their time in the operating room it is also important to assess clinical competence in their interactions with patients in other settings. It has also become clear that non-technical skills such as decision-making, leadership, teamwork, and communication skills also affect the performance of the surgeon and in recent years assessment of these non-technical skills has moved forward considerably. Any new WPBA must undergo a formal evaluation to confirm its feasibility, acceptability, validity, and reliability. To ensure face validity they should comprise direct observation of workplace tasks while for reliability to be confirmed there should be multiple measures of outcomes using several observers with frequent observations. Any assessment needs to be feasible within the context of the training and working environment and the intention was that once the trainers had been trained in the use of the assessment process, they would be cost effective.

There are a variety of WPBAs that are routinely used in different countries and in different specialties globally. In order to try to demonstrate how they can be linked together to deliver a rounded, holistic assessment of the performance of a surgical trainee, the system used to assess surgical trainees as they progress toward certification in the United Kingdom is described below. There have been many variations of this model described but the principles underlying each system are largely similar.

6.3.2 Competence Assessment in Surgical Training in the United Kingdom

A competency-based curriculum was introduced in the United Kingdom in 2007, providing a framework for surgical training through to consultant level. There was a syllabus that defined the knowledge, clinical judgment, technical and operative skills and professional skills and behaviors that were needed in order to progress. The curriculum was accessible online [11] and contained the most up-to-date versions of the specialty syllabuses. Some aspects of the early years' syllabus were common to all specialties, but were increasingly singular as training in each discipline advanced. The curriculum was founded on a number of key principles including

- A common format and similar framework across all the specialties,
- Systematic progression through to the certification,

- Standards that were underpinned by robust assessment, and
- Regulation of progression through training by the achievement of outcomes that were competence-based rather than time-based.

The purpose of the assessment system was first to determine whether trainees were meeting the standards of competence and performance specified at various stages in the curriculum, secondly to provide comprehensive feedback to the trainee, and thirdly to determine whether trainees had acquired the knowledge, clinical judgment, technical skills, and behavioral and leadership skills required to practice independently. The individual components of the assessment system were WPBAs covering knowledge, clinical judgment, technical skills and professional behavior and attitude (Table 6.2), a surgical logbook, knowledge-based examinations, learning agreements, and the supervisors' report with a summary annual review of competence progression. In recent years additional workplace assessments have been added including assessment of teaching and an assessment of audit.

The WPBAs were criterion-based with the primary purpose being to provide feedback between trainers and their trainees [1, 10]. They were designed to be trainee-driven but inevitably there were occasions when they were trainer-triggered. The accumulation of WPBA outcomes was one of a range of indicators that informed the annual review. As a consequence, a decision could be made whether there had

Table 6.2 Workplace-based assessments used in the UK surgical training system

Method	Main competences assessed
Case-Based Discussion (CBD)	Assesses clinical judgment, decision-making, and the application of medical knowledge in relation to patient care in cases for which the trainee has been directly responsible. The process is a structured discussion between the trainee and supervisor about how a clinical case was managed by the trainee
Surgical Direct Observation of Procedure (DOPS)	Assesses the trainees' technical, operative, and professional skills in a range of basic diagnostic and interventional procedures during routine surgical practice. Surgical DOPS is used in simpler environments and procedures than a PBA (see below)
Procedure-Based Assessment (PBA) [12]	Assesses trainees' technical, operative, and professional skills in a range of procedures during routine surgical practice. The assessment is supported by descriptors outlining desirable and undesirable behaviors that assist the assessor in deciding whether or not the trainee has reached a satisfactory standard on the occasion observed
Clinical Evaluation Exercise [13] (CEX)	Assesses the trainees' clinical and professional skills in a clinical situation. The assessment involves observing the trainee interact with a patient in a clinical encounter
Observation of Teaching (AoT)	Assesses instances of formal teaching delivered by the trainee as and when they arise and provides formative feedback for the trainee
Assessment of Audit (AoA)	The assessment can be undertaken whenever an audit is presented or otherwise submitted for review
Multi Source Feedback (MSF)	Used to assess professional competence within a team-working environment. The MSF comprises both a self-assessment and assessments of a trainee's performance from a selection of workplace colleagues

been satisfactory progression and consequently whether the trainee could progress or complete training. The trainee's educational supervisor had a key role in judging whether the trainee required more than the minimum number of assessments. In principle, the assessments needed to be started early and continue regularly with the expectation that there would be evidence of progression throughout the training period. All the assessments in the curriculum included a feedback element. Educational supervisors were able to provide further feedback to each of their trainees through the regular planned educational reviews and appraisals that occurred at the beginning, middle, and end of each placement, using information contained in the trainee portfolio and feedback from other trainers in the workplace.

6.3.3 Assessment of Technical Skills

For surgeons, it is perhaps inevitable there has been a historical focus on the assessment of technical skills. The most widely used WPBA in this context is probably the objective structured assessment of technical skill (OSATS) which was developed to assess the performance of Canadian surgical trainees and includes seven operative competence scores; respect of tissue, time and motion, instrument handling, suture handling, the flow of operation, knowledge of procedure operative performance, and final outcome [14]. There are now many variations on the OSATS scale including the operative performance rating scale (OPRS) [15] and the global rating index for technical skills (GRITS) [16].

The procedure-based assessment (PBA) was originally developed by the Orthopaedic Competence Assessment Project in the United Kingdom [17] and has since been adapted for all surgical specialties [12]. The assessment method uses two principal components: a series of competencies within five domains and a global assessment that was initially divided into four levels but has now been expanded somewhat to include assistance at an operation (Tables 6.3 and 6.4). In contrast to many other technical skills tools, there are domains for preoperative planning (including consent) and post-operative planning. The highest rating within the global assessment is the ability to perform the procedure to the standard expected of a specialist in independent consultant practice within the UK National Health Service.

Whichever tool is used there is value in obtaining multiple assessments from multiple observers. For instance, the initial validation study of the PBA suggested that there was excellent reliability when more than three assessments were used for a particular procedure or when two observers each undertook two assessments [12]. Because the PBA is procedure-specific, all of the core surgical procedures within a specialty-training pathway need to be assessed separately.

There remains interest in other, more automated ways of measuring operative competence [18, 19]. For instance, it is possible to analyze a surgeon's movements in a variety of ways including the use of sensors attached to the surgeon's hands and

Table 6.3 The domains of the Procedure-Based Assessment [12, 17]

Domain	Competencies assessed
Preoperative planning	Including • Knowledge of anatomy and pathology • Choice of equipment and materials • Checking of equipment and materials • Patient marking • Checking of patient records • Confirmation of patient and indication for procedure
Preoperative preparation	Including • Theater checks including consent • Effective briefing at the theater team • Positioning of the patient • Skin preparation • Availability and deployment of equipment and materials • Ensuring appropriate drug administration
Exposure and closure	Including • Understanding of optimal access • Adequate exposure • Sound wound repair where appropriate
Intraoperative technique	This will vary from procedure to procedure but should include; • A logical sequence of surgical steps • Careful tissue handling • Appropriate hemostasis • Careful use of instruments with the economy and safety • Ability to respond to unexpected events • Appropriate use of assistant • Careful communication with theater team including anesthetist
Post-operative management	Including • Effective transfer from theater to bed • Clear operation notes • Clear and appropriate post-operative instructions • Management of specimens

Table 6.4 Global assessment of the PBA [12, 17]

Level	
0	Insufficient evidence observed to support a summary judgment
1a	Able to assist with guidance
1b	Able to assist without guidance
2a	Guidance required for most or all of the procedure
2b	Guidance of intervention required for key steps only
3a	Procedure performed with minimal guidance or intervention (needed occasional help)
3b	Procedure performed confidently without guidance or intervention but lacked fluency
4a	Procedure performed fluently without guidance or intervention
4b	Procedure performed fluently without guidance intervention and was to anticipate, avoid ordeal with common problems or complications

this approach has been used on the da Vinci robotic system. This sort of approach has suggested that experts use fewer, smoother movements and that they manipulate tissues more gently.

6.3.4 Assessment of Non-technical Skills

In recent years, there has been increasing emphasis upon the ability to measure the non-technical skills of a surgeon. We know that there is good evidence that when analyzing adverse events in healthcare, we see that many of the underlying causes reflect non-technical aspects of performance rather than a lack of technical expertise. These non-technical skills might be defined as "*those critical cognitive and interpersonal skills that underpin technical proficiency*." The most widely used tool in the theater environment is the non-technical skills for surgeons (NOTSS) instrument, which has four domains: situation awareness, decision-making, communication and teamwork, and finally leadership (Table 6.5) [20, 21] (more details in Chap. 17). The NOTSS tool can be used by the surgical supervisor but there is often added value from using other members of the theater team to additionally assess the trainee.

6.4 Challenges and Future Directions

The introduction of competency-based training in the UK exemplifies some of the challenges that can occur [22, 23]. First, it is essential that the training faculty be trained to use the tools appropriately. If the trainers do not know how to use the assessment tools properly, then the results of those assessments will be inaccurate. In the United Kingdom, following the "big bang" introduction of competency-based training in 2007, it was some years before many consultant trainers were trained to

Table 6.5 NOTSS summary rating form [20, 21]

Domain	Elements
Situation awareness	Gathering information Understanding information Projecting and anticipating future state
Decision-making	Considering options Selecting and communication option Implementing and reviewing decisions
Communication and teamwork	Exchanging information Establishing a shared understanding Coordinating team activities
Leadership	Setting and maintaining standards Supporting others Coping with pressure

use the WPBAs, although this now has been achieved. A second problem has been the tendency by trainers and trainees alike to view these tools as a "tick-box" exercise, with inadequate emphasis upon delivery of formative feedback and with the consequence that the intended learning for the trainee is not achieved. Thirdly there has been a (perhaps) natural reticence for trainees to avoid receiving negative feedback. As a consequence, there has been a tendency for trainees to leave their assessments until they feel that they have mastered the technique, thereby ensuring a positive outcome to the assessment. At the same time trainers, not always wishing or comfortable in providing negative feedback, might not always identify areas for improvement by the trainee. As we move forward, there are still quite a variety of views on when and how frequently assessments should be undertaken [2] and we do perhaps need to understand these issues better.

6.4.1 Entrustable Professional Activities

Another area of difficulty reflects the granular nature of the WPBAs. They were designed to assess relatively small components of the daily activities of a surgical trainee. The difficulty comes in trying to translate these assessments into day-to-day clinical practice. One concept that has sought to resolve this problem is the concept of the entrustable professional activity (EPA) [24, 25]. All (certified) clinicians make daily judgments regarding the trainees with whom they work and what they "trust" them to do on their own and to what extent they require supervision. The EPA uses this principle to describe the extent that a supervising surgeon will trust the trainee to undertake a piece of work. A definition of an EPA might be "*a unit of professional practice that can be fully entrusted to a trainee, once he or she has demonstrated the necessary competence to execute this activity unsupervised*."

As such the intention is that EPAs are not intended to replace WPBAs, but instead to translate them into clinical practice by describing different types of work. So, for example, while a WPBA assesses whether a trainee is competent to take a history from the patient with a particular clinical problem (i.e., it is a descriptor of the physician), the EPA judgment is whether the trainer trusts the trainee to undertake an outpatient clinic independently (i.e., it is a descriptor of work). Such a judgment will inevitably involve assessment of the trainee's knowledge, of their interpersonal skills, of their professionalism, and of their clinical skills, all of which might have been previously assessed by a basket of WPBAs.

6.4.2 The Role of Assessment in Simulation

There is good and increasing evidence that simulation, both technical and non-technical, can enhance learning and aid progression [26]. There is a natural tendency to believe, for instance, in relation to technical skills, that simulation has its primary role in the early part of surgical skills training but there is increasing evidence that appropriate simulation can be helpful in all stages of the transition from novice to competent to proficient to expert. However, for simulation to have the maximum effect the same principles of assessment should apply. Assessment will, after all, drive learning and therefore appropriate assessment with appropriate feedback during a simulation exercise will enhance progression. Many of the tools described above, such as the PBA, can be used in a simulated setting but a number of additional tools (so-called simulation-based assessments or SBAs) have been developed specifically for the simulated environment [26]. Such tools should ideally predict real-world performance, although at present that has not conclusively been demonstrated. A systematic review of the association between simulation and patient outcomes concluded that while there was often a correlation between the two, if there was a marked variation in trainee performance, then that translated into weaker performance [27].

6.5 Summary

Although historically, surgical training was delivered via an apprenticeship model, multiple drivers have now dictated that surgeons now need to demonstrate their competence in order to be certified to practice independently. There are a number of feasible, acceptable, valid, and reliable tools that have been developed to assess the clinical, technical, and non-technical competence of a surgeon and these are now widely used in training programs around the world. Although there remain some problems with the implementation of competency-based programs they remain the likely future direction of assessment within surgical training. In the near future the concept of "entrustable professional activities" will likely be used to translate these competencies into clinical practice.

Key Points

- It is generally accepted that for a surgeon to practice independently, he or she will require a range of clinical, technical, and non-technical skills.
- There are a range of validated tools, called workplace-based assessments, to assess clinical, technical, and non-technical skills.
- Many training programs have introduced workplace-based assessments as a central component of competency assessment.

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Chapter 7
Procedural Training Simulators

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Abbreviations

HoLEP	Holmium Laser Enucleation of the Prostate
PCNL	Percutaneous Nephrolithotomy
TURBT	Transurethral Resection of the Bladder Tumor
TURP	Transurethral Resection of the Prostate

7.1 Introduction

In the last two decades, surgical training and education have abandoned the master–apprentice model, which has worked for centuries to school proficient surgeons and gradually adopted strategies followed by industries such as aviation and the military, which heavily rely on simulation training before real-life exposure [1, 2]. The traditional "see one, do one, teach one" training model [3] has lost acceptance in

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surgical training during the twenty-first century, and by applying simulation, a large part of the procedural learning curve can be acquired using training models [4]. Historically, the first medical simulators were simple models of human patients [5]. By definition, a model is a representation, generally in miniature, to show the construction or appearance of something, or a simplified version of something more complex. Models are utilized to analyze and solve problems or make predictions when creating an original surgical condition (procedure) is impossible. They represent real-world systems or concepts meant to be tested, analyzed, or used for training purposes through simulation. On the other hand, simulation is implementing a model/simulator over time that brings this model to life and demonstrates the behavior of a particular object or phenomenon under certain conditions. Especially procedural training simulators model some aspect of human anatomy or surgical step, which facilitates a learning activity by simulating characteristics of that anatomy or step. As trainees have different learning rates and skills, not all would have sufficient time to master a surgical technique on time with the master–apprentice method. Simulation training allows convenient learning in that the trainee can learn when time allows and does not have to wait for a particular operation when there is a scarcity of in-patients upon which to operate. When training in the operating theater, much operating time is lost, and therefore simulation training does not slow the progress of the lists or reduce staff time for training. On the contrary, it allows training out of the operating theater to be tailored to the individual's needs and avoids the embarrassment of slow progress around peers. Additionally, the endpoints of a specific task can be altered to meet the trainee's needs, and the simulated operation can be abandoned when the trainee feels saturated.

By focusing on Urology, the most significant number of procedural training simulators and subsequent validation works have been carried out in the field of endourology, laparoscopic and robot-assisted surgery [6–8]. On the contrary, open urological procedure simulation has only seen a handful of validated models [9]. Different tools have been used over time to help surgeons acquire technical skills. Despite their simple composition, even sponges proved to be as helpful as modern virtual simulators in acquiring specific maneuvers, like intracorporeal knot tying. Nevertheless, it is easy to understand today the multiple aspects that make the sponge "outdated" by comparing it with a sophisticated simulator. In order to gain a better understanding of it, we need to consider training platforms from different perspectives. This chapter aims to give a broad view of different types of models/simulators applied in Urology. Additional information about their advantages and limitations will be provided. An extensive list of all available simulators is beyond the scope of this chapter.

7.2 Key Features of Simulators

Despite the increase in surgical simulator popularity among urologists, simulators must be rigorously evaluated to demonstrate their educational effect before they are used in training and assessment. Basic parameters that need to be taken into account are the acquisition of valid ***source information*** about the relevant selection of key characteristics and behaviors and ***simplifying approximations*** and ***assumptions*** within the simulation of a surgical procedure.

A simulator's ***fidelity*** shows how "realistic" it is and plays an essential role in choosing an appropriate simulation for a specific task. The degree of realism or authenticity ranges from entirely artificial (***low-fidelity***) to an actual real-life situation (***high-fidelity***). The level of fidelity should be appropriate to the type of task and training stage. A novice can achieve similar or higher skills transfer with a simple simulator than with a complex training aid like a simulated environment [10, 11]. More experienced trainees in more advanced training levels would benefit from higher fidelity levels by demonstrating higher levels of speed and practice of a task. A simulator is best utilized in alignment with educational goals that underpin its use within a program.

A surgical simulator's ***reliability*** reflects the reproducibility and precision of the test or testing device [12].

The ***validity*** of the simulation outcomes reflects how likely they are to happen in real-life or the confirmation that a simulation product or service meets its users' needs. A surgical simulator is related to a type of analysis that has the ultimate goal of understanding its accuracy and credibility. Nevertheless, the more we get closer to scientific analysis and, especially, to healthcare needs, the more it becomes complicated to provide a clear definition of the term. In the last two decades, the simulators' validation has been chiefly based on questionnaires or comparisons between experts' and novices' performance on a model.

Different types of validity include [12, 13]:

- ***Face validity*** reflects different opinions, including of amateur surgeons, regarding the realism of the simulator. It is assessed using surveys and is considered to be subjective, offering the lowest level of evidence.
- ***Content validity*** reflects the opinions of experts about the simulator and how appropriate and representative is this simulator for training. It is also assessed using surveys and is considered subjective, offering the lowest evidence level.
- ***Construct validity*** measures the simulator's ability to assess and differentiate between the *level* of experience of an individual or group of trainees over time (within one group) or the ability to distinguish between different levels of experience (between groups).
- ***Discriminant validity*** represents a more intricate form of construct validity by differentiating different ability levels in groups with *similar* experience levels.
- ***Concurrent validity*** reflects the comparison of a new model against the older and gold standard, usually by utilizing Objective Structured Assessment of Technical Skills (OSATS).
- ***Predictive validity*** correlates performance during simulation with performance in the operating room and is usually measured by OSATS.

After years of research, experts know that it might be incorrect to confirm a simulator's validity just by following the mentioned metrics. For example, a simulator is valid and effective for teaching technical skills to an individual trainee while being not useful to another. This could be explained by the presence of several variables, such as the type of applied curriculum or the tutor involved. Furthermore, the validity of a simulator is not strictly related to its realism but also the expected simulation results.

During the last years, construct validity has gained more value, as it provides us with the information of whether the previous experience of a surgeon has an impact on his behavior on the simulator. Today, international literature considers the construct validity and assessment methodologies as the core of surgical simulators' evaluation [14, 15]. Consequently, there has been recently a redefinition of the concept of validity and the addition of updated aspects, namely test content, response processes, internal structure, relationships to other variables, and consequences of testing [16].

- ***Test content*** reflects the ability of the surgical simulator to produce the expected outcomes. A cohort of experts usually decides it.
- ***Response process*** is the analysis of the assessment methodology and its ability to reflect and score the trainees' observed performance.
- ***Internal structure*** also focuses on assessment methodology, its replicability, and statistical reliability.
- ***Relationship to other variables*** correlates the performance with known measures of skill or ability, like the trainee's clinical background.
- ***Consequences*** are considering the relationship between the assessment and performance improvement in the operating theater.

Therefore, validation not only considers the opinion of a subject, either novice or expert, or the superiority in comparison with the previous gold standard, but it also focuses on how a simulator was designed, how relevant is the background of the trainee, and how critical is the assessment to understand the actual acquisition of skills. Nevertheless, validity research is still hampered by a paucity of accepted definitions and measurement methods [17]. Consensus on guidelines on validating surgical simulators for the development of training programs would be helpful. Development and validation of training models should be based on a multidisciplinary approach involving specialists (teachers), residents (learners), educationalists (teaching the teachers), and industrial designers (providers of teaching facilities).

7.3 Types of Simulators

The trainee usually interacts with a physical object which can be a manikin or part of a human or animal body. The skills that can be acquired are technical and non-technical. Technical skills can be acquired using several different simulation modalities, including virtual reality (VR) simulators, synthetic models, animal tissue or live animals, and human cadavers, each with its advantages and disadvantages. Non-technical skills simulation training has not received as much attention but is becoming increasingly popular in the clinical wards and operating room setting. This type of training can be conducted in the operating room via full-immersion and high-fidelity operating room simulation. Various classifications on the categorization of simulators can be found in the literature (Table 7.1).

Table 7.1 Classifications of Simulators

Study	Categories of simulators
Meller [18]	Patient and/or their disease process Procedure or diagnostic test or equipment being used Physician or paraprofessional Professor or expert practitioner
Torkington et al. [19]	Inanimate artificial tissues and organs Fresh tissue or animal models Virtual real and computerized simulation Actors role-playing a trauma simulation
Ziv et al. [20]	Low-tech simulators, Simulated/standardized patients, Screen-based computer simulators, Complex task trainers (including virtual reality) Realistic patient simulators
Kneebone [21]	Model-based (those based on physical models), Computer-based (those that use computers to create illusions of reality, including virtual reality) Hybrid (those combining physical models with computers)
Maran and Glavin [10]	Part-task trainers Computer-based systems Virtual reality and haptic systems Simulated patients Simulated environments Integrated simulators – Instructor-driven simulators – Model-driven simulators
Beaubien and Baker [22]	Case studies/role play, Part-task trainers Full mission simulation
Cumin and Merry [23]	Interaction (hardware-based, screen-based, or virtual reality-based), Physiology (no physiology, script-controlled, or model-controlled) Use for teaching (knowledge, cognitive skills, or psychomotor skills
Alinier [24]	Level 0—Written simulation Level 1—3-D models Level 2—Screen-based simulators Level 3—Standardized patients Level 4—Intermediate fidelity patient simulators Level 5—Interactive patient simulators

7.3.1 Synthetic Models

Synthetic models (Fig. 7.1) have been used for a considerable period in the field of surgical simulation. However, the increase in demand for synthetic models appeared after introducing minimally invasive surgery in the early 1990s. It was then when a Bristol-based company named “Limbs & Things” was established. This company specialized in three-dimensional models for training in minimal access surgery and quickly identified the major need to develop materials, molding, and casting techniques to allow soft tissue to be simulated effectively. Ever since synthetic models

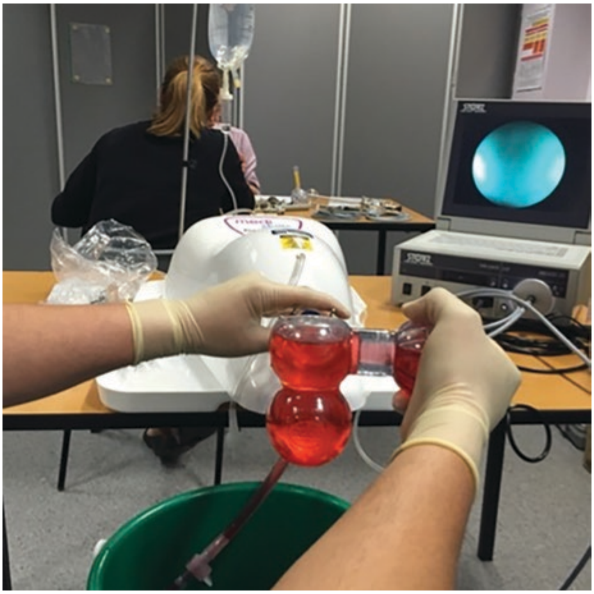

Fig. 7.1 Bladder wash-out simulation (Courtesy Medical Education Department, St James's University Hospital, Leeds, UK)

have been applied in various specialties [25–27]. In Urology surgical training, synthetic models have been mainly used in the laparoscopy [28–30], as intra-corporeal suturing is one of the most difficult advanced surgical skills that surgeons must acquire to perform advanced laparoscopic surgical procedures. Synthetic models have also been utilized in the simulation of scrotal examination [31], open urology [32–35], robotic surgery [36], ureteroscopy [37–44], PCNL [45], TURBT [46], TURP [47], and HoLEP [48] during the last decade, demonstrating face, content, and construct validity (see Chaps. 10, 11, 12, and 14 for more details on these simulators).

Although usually simple in composition, these simulators are invaluable tools in training and assessment of surgical skills. The main advantage is their availability, as trainees can even gather all components and build a model themselves. They are also characterized by good face validity in that they usually achieve a realistic representation of human anatomy during a surgical step. On the other hand, the trainers may develop their tasks for the training of particular surgical skills. Additionally, in comparison with animal tissue or cadavers, synthetic models do not have health and safety issues associated with their use. Therefore, there are no limitations in the location of training, as trainees can even train with them at home. Nevertheless, in some cases, especially certain steps including the use of fluids (e.g., bleeding simulation) can make the tasks very messy. In these situations, their use is more appropriate in settings like dry skills laboratory is recommended.

These models have other more substantive problems. Some of them are believed to be anatomically incorrect. Additionally, modern synthetic models can also be quite expensive in the training situation. Especially for laparoscopic intracorporeal suturing, some material still has a discrete "use" life since only so many incisions can be made on it before it becomes unusable. Some commercially available materials can only be used once. Moreover, simple models do not always respond the same way as in human or animal tissue. For example, when teaching certain types of suturing techniques with synthetic models, the artificial tissue tends to rip, making simulation exercises very difficult.

7.3.2 *Animal Tissue Models*

Animal tissue material includes pieces of chicken, pork, liver, or bowel (Fig. 7.2). It is one of the most basic simulation models that have been successfully used in the surgical simulation for decades. Surgeons can use these models for training a wide range of surgical skills, from suturing to the making and closing of an incision. Additionally, these types of models are readily available, distributable, inexpensive, and disposable. Another advantage of animal tissue is the appropriate trainee exposure with real tissues, including fragility and consequences of inappropriate or rough tissue handling. As a result, these models usually achieve good face validity for the trainee, and for the trainer, they give a decent idea of how the trainee will handle human tissue. Animal tissue models have been utilized in the fields of endourology [37, 43, 49–51], laparoscopy [52–57], and robotic urology [58, 59], demonstrating various levels of validity.

One of the major disadvantages of working with animal tissue includes the requirement of special facilities to assure health and safety [60]. Unique benches, cleaning material, and freezers for hygiene and conservation reasons are always deemed necessary. The limited shelf life and a certain number of uses before

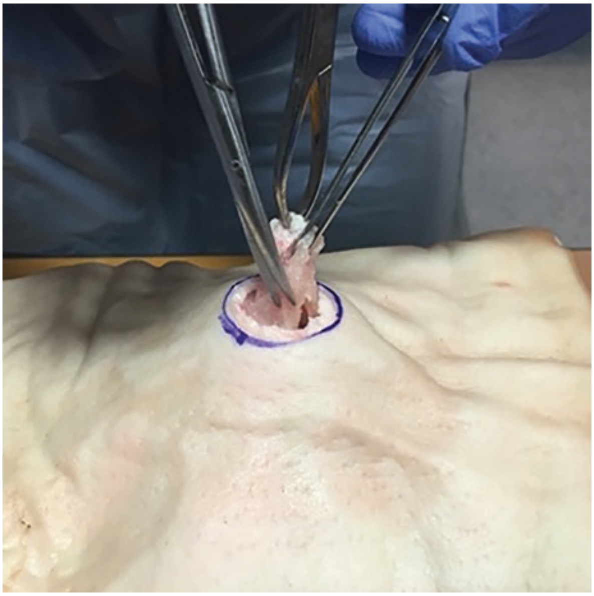

Fig. 7.2 Porcine model to teach stoma formation (Courtesy Medical Education Department, St James's University Hospital, Leeds, UK)

becoming a health hazard are additional handicaps of animal tissue models. A further difficulty is the problematic assessment of the trainee's performance, as the trainer should observe the whole training exercise. This requirement is that it is crucial to assess the finished product of the operation and how the trainee achieved it in surgery. Therefore, the trainer should remain cognizant that the look of the finished product can be deceiving. This sort of problem is not only a limitation of basic types of simulation models, but it also occurs with more advanced and costly simulators.

7.3.3 Virtual Reality (VR) Simulators

Virtual reality is the interface between humans and computers that simulates a realistic environment, presenting a three-dimensional (3D) digital setting while enabling human interaction (Fig. 7.3) [61]. Jaron Lanier introduced the term in the field of commercial enterprise during the late 1980s. Since then, it has mainly been utilized in the aviation industry for years [62]. Many similarities can be drawn between pilots and surgeons as both have to learn to manage stressful and potentially life-threatening situations that are also unpredictable and subject to instant changes. Hence, the benefits of VR simulation noted in the aviation industry have inspired VR training attempts into surgical training.

From a surgeons' perspective, the manufacturer needs to define the procedures or surgical steps that would benefit from training and provide training for standard procedures or steps. The simulator should provide accurate details, the precision of anatomy, and a high level of interaction. From a manufacturer's perspective, different factors, including the number of trainees and the frequency a surgeon performs a specific procedure, need to be considered. Development costs prohibit the creation of simulators for more specialized or rare procedures.

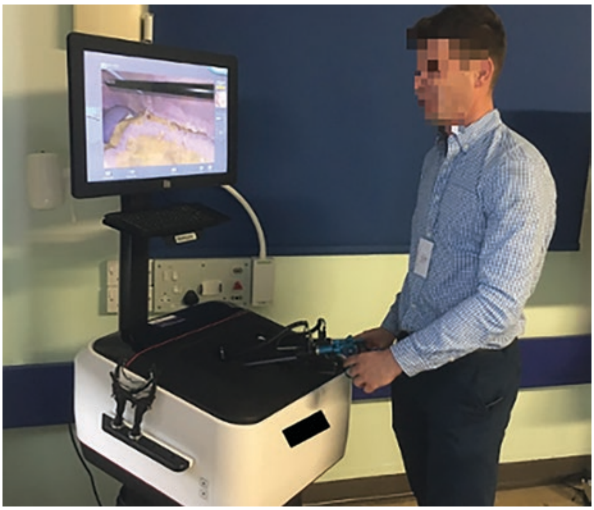

Fig. 7.3 High-fidelity virtual reality simulator (Courtesy Medical Education Department, St James's University Hospital, Leeds, UK)

The main features of VR simulators include the following [63]:

- ***Visual reality:*** Simulators should have a high resolution to look realistic.
- ***Physical reality:*** The simulator needs to be interactive, and devices need to react to forces applied by the trainee. The organs should look elastic, and there should be dynamic realism when organs and tissues are touched or grasped; they need to bend and deform, as they do in reality.
- ***Physiological reality***: Tissues need to show signs of life, like organ peristalsis, bleeding, and muscle contractions. They also need to react to reality when manipulated.
- ***Tactile reality:*** The trainee should feel forces and pressure between the medical device and the tissue.

Virtual reality allows learning real procedure steps that have been simulated on computers without causing any patient discomfort or risk [64]. It also permits the trainee to practice specific procedure steps as frequently as needed before undertaking the entire procedure. The trainee then gains maximum benefit when simulations closely approximate the natural environment in which the particular skill will eventually be used. When this repetition is combined with appropriate feedback from a tutor directed at specific strengths and weaknesses, the training session becomes ideal. Furthermore, simulators usually provide an "action replay" option to allow performance evaluation. Many VR systems offer objective data collection, therefore allowing objective feedback of variables such as the time taken to complete the procedure, error rates, and economy of motion. The trainee and tutor can then assess and evaluate the performance improvement. The latest evolution of VR surgical training is the ***high-fidelity full physics VR simulator***. This type of VR training is probably the "holy grail" in medical simulation as it simulates in real-time patient anatomy, physiology, and pathology that has been rendered from the imaged data of actual patients. Moreover, it simulates real surgical instruments that appear and interact with the simulated tissue achieving a high level of realism, and surgical cases are developed from actual patients. VR simulators have been utilized in the simulation of various endourological procedures like cystoscopy and ureteroscopy [65–76], PCNL [77–79], TURBT and TURP [80–86], and laser prostate surgery [87–92]. Numerous studies have also demonstrated various levels of validity of VR simulators in the fields of laparoscopy [93] and robotic surgery [94–108].

However, VR simulation, in general, is still on the ground floor of surgical training. Transfer efficiency ratios need to be developed for VR simulators to give trainers an indication of the equivalence of time spent on a VR simulator in terms of time spent operating on actual patients [109]. A moderate stress element should also be added to VR systems, as this is known to be the optimum learning environment. Furthermore, despite the excellent graphics available, there remains some minor delay in the screen-refresh rate so that rapid interaction between the computer and user is still lacking. The rapid improvement processing power of computers should solve this problem shortly. Moreover, current VR simulators are handicapped by the lack of haptic feedback and sensory input of pressure or texture. Deformity of organs by "contact" with the instruments and bleeding, tissue damage, muscular contraction, and organ peristalsis are usually not adequately simulated. Computer algorithms need to detect contact between objects and the presence of forces between them [110]. High-fidelity simulators also require dedicated space in a temperature-controlled room, very knowledgeable technical support, and gentle handling. Finally, available systems are also costly and not affordable by all training institutions, raising issues of the source of funding for VR training. Hence, one may understand that a good simulator is not just the one that is *looking* better, but the one which is better at following the requirements set concerning the expected outcomes.

7.3.4 Augmented Reality (AR) Simulators

Augmented reality provides a means of inserting digital information, like visual objects or sound, into a natural environment in real-time. In medicine, AR refers to the alignment or superimposition of intra- or preoperative imaging onto an actual patient's images or video. The hardware includes any commonly used smart device (phone/tablet) or specialized headgear [111]. The surgeon combines essential visual information from the operative field with ultrasound, computed tomography, or magnetic resonance imaging that would otherwise play a passive role within the operating room. Reconstructed images can then be registered onto anatomic landmarks and tracked by the computer according to tissue manipulation and camera movements. As a result, a seemingly transparent visual anatomy of the internal structures or lesions through the overlying tissues is presented to the surgeon. Nevertheless, AR is still in its infancy, also in the field of surgical simulation, as only a few validation studies have been conducted [112]. Only limited urological studies, especially in robotic surgery, have assessed AR's impact on surgical simulation [113–118]. Its significant limitations include cost, lack of privacy, inaccuracy in image registration, and poor navigation precision. Furthermore, it is important to protect the confidentiality of patient medical information. There are guidelines for safeguarding the healthcare providers, and third parties with patient information are managing the data with respect and responsibilities [119]. Simulation environments might help with broader adoption of the technology, and practice using AR in a virtual reality setting could reduce the concerns against its adoption in everyday clinical practice (see Chap. 25 for more details on immersive technologies).

7.3.5 High-Fidelity Live Animal Tissue Models

Surgery and interventional medical disciplines have used live animals in training for decades. Training under natural operating room conditions with real surgical instruments offers reassurance for surgeons. It also provides valuable information about the instrument's behavior or interaction with natural anatomy. For example, in comparison to VR simulators, it is much easier to simulate the behavior of an electrical cautery instrument close to moist live tissue. Making the initial incision, operating on real vascularized and beating tissue, and practicing wound closure are additional advantages to using live animals for training purposes. In Urology, live animals have been utilized worldwide in numerous laparoscopy [30] and endourology [37, 43] courses. However, there are also various disadvantages associated with training on live animals, not least of the ethics associated with it. Significant costs related with housing the animals, feeding them, and providing a dedicated operating room equipped to a similar level as a hospital operating room, are additional handicaps. Moreover, a vet technician, a veterinary surgeon, and an anesthetist must always be present throughout a surgical procedure. All the above aspects of animal work significantly increase the costs of training on animals. Regarding trainee performance assessment, it is sometimes difficult to achieve it without sacrificing the animal. On the other hand, in a bench-top simulation model, it is relatively easy to assess performance by simply removing some simulator components and examining suture quality. The live animal simulation model is affected by the same issues as cadaver simulation training. Lab animals do not provide any measurable information about the learning session and cannot be used for specific procedural training. By taking into account the ethical concerns and the animal rights issues that vary from country to country, it is clear why also lab animal surgical training courses constantly decreased in the surgical simulation field through the years.

7.3.6 Human Cadavers (Fresh Frozen, Embalmed)

Vesalius was the first who tested published anatomical information against the facts revealed by cadaveric dissection in 1542 [120]. Since then, human cadavers have always been and will probably play a significant role in exploring human anatomy during the medical training [121]. In the field of surgery, cadaveric courses during training are still prevalent among experts and trainees. In particular, trainers value developing a touch-based topographical map of the human anatomy by a trainee surgeon. Touch-based learning is one of the main advantages of cadaver simulation, as this aspect continues to require further development in the field of VR simulation. Dissection constitutes a necessary exercise in developing touch-based skills, which are essential in the surgery [122]. The value of "haptics" that currently exists in medical simulators, in general, is still under debate, despite the lengthy investigation by numerous study groups. Additionally, the cost of adding haptics components to a VR simulation is enormous. Another significant advantage of cadaveric work is that it offers the teaching and understanding of deeply located structures and a rational approach to understanding the three-dimensional organization of anatomical structures and their dimensions, densities, and the strength of different types of tissue [123]. In summary, experts believe that human cadaver training paves the way for surgeons to learn the techniques and the instrumentation and is the key to their medical education. Most importantly, human cadavers are in much demand for postgraduate surgical training courses such as laparoscopic or robotically assisted procedures.

Despite the above-mentioned advantages of cadaveric simulation training, a review on cadaver use during the 1980s led to a significant instructional time reduction [124]. Along with the rapid evolution of other types of simulation, including VR, several undeniable cadaveric training drawbacks have probably led to this fact.

- ***Time-consuming:*** cadaver preparation and dissection is an overly time-consuming activity.
- ***Labor intensive/shortage of anatomists:*** partly due to lack of appropriately trained and qualified faculty
- ***Cadaver unavailability*****:** Donations of human bodies for medical research have declined in recent years in many countries, probably due to a marked decline in public confidence in the medical profession.
- ***Undesirable post-mortem changes:*** cadaveric anatomy is different from living anatomy and can be misleading for a trainee.
- ***Expensive:*** cadavers are costly to obtain, embalm, store, maintain, and dispose of.
- ***Unesthetic:*** *Cadavers* smell, look ugly, and are repulsive.
- ***Potential health hazard:***
  - *Dangers of embalming fluid components* (formaldehyde, xylene)
  - *Danger of infectious diseases like* transmissible spongiform encephalitis, human immunodeficiency virus, tuberculosis, and hepatitis
  - *Psychosocial impact* (fear and anxiety)

In addition, cadaveric surgical simulation has been criticized for altering tissue quality caused by the embalming/preservation technique [125]. Simulation of advanced surgical operations in traditionally embalmed cadavers is often impossible due to the tissue rigidity and alteration of quality in color and flexibility. Using fresh frozen cadavers is, therefore, a popular option for such a training [126, 127]. Nevertheless, fresh cadavers lack the longevity period to undertake multiple surgical techniques and carry the risk of infectious diseases. Additionally, the construct validity of fresh frozen cadavers has only recently become established as a training tool in minimal access surgery, including endourology and robotic surgery [126, 128–130].

The cadaver embalming method developed by Walter Thiel in the 1990s [131, 132], preserves volume, shape, color, and echogenicity of organs and tissues, enabling a comparable dissection to that on a fresh-frozen cadaver. This method provides long-term preservation lasting several decades, has low toxicity, and does not need cooling, just the cadaver's periodic immersion in a preserving solution. The embalming fluids are based on a mixture of water, glycol, strong oxidizing salts, and minor quantities of bactericidal/antifungal agents. This type of preservation allows permeability of vessels and flexibility of tissues that are not shrunk or soaked. More harmful components such as formaldehyde, 3-chloro-4-cresol, and morpholine are only used in minute concentrations, which improves safety in working with the cadaver. Additional perfusion solutions are also prepared from the general basic solution. These solutions are pressure injected through the vessels or the digestive tract to fix the cadaver's different compartments. The whole process lasts several days and is followed by immersion of the cadavers in a similar solution, where the slow chemical reactions of the fluids and tissues are completed, which lasts 6 months. The embalming process can be followed by the injection of colored silicon (m-polymer) into the veins and arteries [133], creating a highly realistic and lifelike approach for a variety of surgical training techniques. Thiel-embalmed cadavers are suitable for training in most surgical specialties [134–137]. Nonetheless, despite its advantages mentioned above, Thiel's method is not widely recognized and applied in only 10% of anatomic laboratories globally [138]. Disadvantages to Thiel's method have been described, highlighting the minority of trained personnel in the technique, relatively higher costs, and the fixation process's long duration [137, 139]. Finally, only a few Thiel-embalmed cadaver studies have been conducted [140], and their construct validity for urologic surgical procedures requires further investigation [141].

To summarize, cadavers have always been considered the best possible training platform because of the almost perfect match with living patients. They have been utilized worldwide for anatomical research and in academic anatomic lectures. A good case can also be made for the development of new surgical procedures by very experienced surgeons. Nevertheless, being perfect for anatomical descriptions, cadavers used for simulation lack some assessment and fidelity requirements. Especially in minimally invasive surgery, the case for acquiring the skills necessary is becoming weaker as virtual reality and bench-top simulators become more sophisticated.

7.3.7 3D Printed Models

Three-dimensional (3D) printing is an additive manufacturing process introduced in 1986 with the polymerization of photosensitive resin by a UV light [142]. The evolution of technology in the field led to the construction of complex 3D models by engineers by utilizing digital objects and different printable materials like polymers, metals, and wax [143]. This evolution led to a rapid expansion of the 3D printing technology in medicine, where it was used to replicate tissues, organs, and organ pathology. In urology, 3D printing proved its value by helping surgeons better understand the anatomy, improve their skills, and identify lesions and their relationship with surrounding structures [144–146]. Organs replicated include the adrenals, kidneys, pelvicalyceal system, and prostate, and different procedure models include a flexible ureteroscopy [42], partial nephrectomy [147], and PCNL [148, 149].

Hollywood special-effect teams initially utilized the "casting" methodology. In the field of surgical simulation, organs are molded with clay starting from a DICOM image. The clay model, after fine detailing, is then covered with plaster to create two separate hard shells. After its removal, the choice material (usually silicon or hydrogel) is poured in and left to cure. Today, a more evolved 3D CAD technology allows a much easier process; as the DICOM image is processed, the 3D model of the organ is created, the two shells are then designed on screen, and finally 3D printed. Materials to pour have also evolved, as recently hydrogel has been introduced to mold more realistic models. Hydrogel is a more sophisticated material to mold, as its high percentage of water makes the models very close to actual organs. However, these models usually dry out faster if not properly preserved.

In most cases, 3D printed models and procedural simulations have demonstrated improvement of short-term technical skills and excellent face and content validity [150]. A significant advantage of these synthetic materials is that they can be highly customized to be harder, softer, stretchable, or textured based on the simulation requirements. Particularly desktop 3D printers can print any plastic, from Polylactic Acid (PLA) to resin, and recycled one. Dedicated production machines can easily model soft plastics, even if not yet printable straight from the 3D printer extruder. However, despite their high quality, production costs currently constitute the significant drawback of 3D printed simulation models. Nevertheless, several tools have made quality products in small series more affordable in the last decade, and 3D software and scanners are always becoming cheaper (see Chap. 26 for more details).

7.3.8 High-Fidelity/Human Patient Simulators

In this setting, trainees are dealing with a physical mannequin that is attached to a computer. This simulation branch, also known as full environment simulation, has been extensively developed and validated by anesthesiologists during the 1960s. Mannequin models were initially developed to teach airway management and resuscitative skills and were coupled with a computer to enhance the simulator's capabilities and realism [151]. These simulators can be used to stage full-scale simulations whereby trainees can encounter realistic monitoring, physiologic response to drugs, and high fidelity. The human patient simulation facility can integrate this practice into a complete curriculum, modify simulation difficulty by the trainers, and enable practice in controlled environments that can capture clinical variation that validly approximates clinical experience. New additions to this group of simulators are continuously coming into the market, simulating different medical scenarios and offering training in complex skills like ultrasound assessment.

Such simulators can add considerably to the training resources of any medical or surgical training program. Nevertheless, mannequins are very expensive and require dedicated space and technical support to ensure optimal training use. Regular software updates that are not inexpensive are also required. An experienced faculty of trainers who run and assess the training curriculum is also deemed necessary. This training facility would probably best fit a team training environment for emergency or critical care scenarios. It could be integrated into a surgical training program during medical school years, intern years, or when the trainee has acquired specific interventional procedural skills that they can implement in an operating room or emergency room environment. Nonetheless, the team training environment scenario may not be an optimal situation to acquire necessary surgical skills. In procedural-based medicine, a nonnegotiable unit of physician performance is the interventionalist's ability to perform the procedure to an adequate level, safely, and in a timely fashion.

7.3.9 Full-Immersion and High-Fidelity Operating Room Simulation

This type of simulation has been implemented in medical simulation training during the last 20 years and currently serves as a valuable clinical research tool used to evaluate devices, people, and systems' clinical performance (Fig. 7.4). The "simulator" is, in this case, a simulated setting, which may be used to address factors unique to complex clinical environments such as an emergency department, an operating theater, or a clinical ward. Simulation facilities can be established in any open space. Simulated clinical scenarios are designed to reflect the setting of interest and used to assess clinicians' performance without increasing workloads or impeding on patient care [152–154]. There is also the added benefit of ensuring no harm to patients, resolving ethical constraints of the clinical environment [155]. The simulated clinical scenario design is complex and consists of a wide range of components to replicate the clinical setting. Numerous studies have reported using full-immersion simulation to assess device performance [156], technical and non-technical skills of clinicians [157–161], and human factors affecting clinical performance [162, 163]. Full-immersion simulation has also been used to discover unpredictable patient safety threats, such as environmental factors [164]. A variety of modalities can be employed, including part-task trainers designed to provide experience in specific skills [165], standardized patients who are actors carefully trained to accurately role-play a patient with a health concern [166], and full-body simulators which are computer driven-mannequins with varying levels of fidelity [165]. The usefulness of this type of simulation is not limited to medical education but also serves as a research tool to investigate important research questions by enabling the study of various

Fig. 7.4 SimMan® with actors for a scenario delivery (Courtesy Medical Education Department, St James's University Hospital, Leeds, UK)

clinical practice aspects that may not otherwise be measurable [167]. A systematic evidence-informed approach is deemed necessary to develop valid and reliable simulated clinical scenarios to be used as an evaluation method in research studies [168].

Full-immersion simulation environments have also been adapted in urology during the last decade. Technical and non-technical skills like teamwork, communication, and decision-making have been evaluated in ward rounds and different operating procedures. Different studies have assessed the impact of simulated ward rounds on clinicians' training in non-technical skills by using a qualitative analysis of the participant feedback [169, 170]. Scenarios included actors as patients and simulated phone conversations, while distractions were directed at different participating team members. Observers stayed in a separate room, where the scenarios were projected on a screen in real-time. Participants positively received the simulated ward round exercises, and non-technical skills showed significant improvements.

Different study groups have applied full immersion to simulate ureteroscopy and of the prostate TURP. Authors have demonstrated a strong correlation between technical and non-technical performance, irrespective of the training received and highlighted that all non-technical skill sets are essential in technical performance. They concluded that both of these skills should be trained and assessed together within the same training curriculum [171]. The same study group could demonstrate the face, content, and construct validity of a full-immersion simulation environment for technical and non-technical skills training during TURP. The authors concluded that this simulation type was a valuable addition to the traditional classroom-based simulation training [172].

Studies have evaluated technical and non-technical skills during laparoscopic nephrectomy procedures [173–175]. In these settings, urology residents have been randomly paired with certified registered nurses and anesthesiologists. Unique polyvinyl alcohol kidney models with embedded tumors and high-fidelity mannequins have been utilized. Scripted events included a patient's anaphylactic reaction to a drug, vasovagal response to pneumoperitoneum, insufflator failure, carbon dioxide embolism, renal vein injury during hilar dissection, and wrong patient or specimen data in a pathology report. Scenarios were rated as helpful in developing communication skills between different team members and making residents aware of unlikely but potential critical errors in the operating room. In the field of robotic urological surgery, little effort has been made to develop non-technical skills assessment tools, and validity evidence supporting these non-technical assessments is limited, including their relationship to technical skills and their impact on surgical outcomes [176].

7.4 Which Is the Best Simulator for the Job?

An ideal simulator:

- Gives automatic responses (immediate feedback) to the trainee's interventions without the need for instructor input.
- Evaluates performance and gives feedback to the trainee after the session without instructor presence.

- Makes learning independent so that a trainee can work through a module without instructor presence.
- Has a low start-up cost.
- Is reproducible, reusable, portable.
- Carries minimal health risks.
- Uses real instruments.

Taking this information into account it is easy to understand that a perfect simulator or model does not yet exist. Different simulators are more suitable for different tasks, procedures, trainees or training programs. Hence, it is recommended for any institution trying to establish a simulation training program or a trainee interested in privately purchasing a simulator to consider several essential parameters.

7.4.1 Advantages and Disadvantages of Different Simulators

Aydin and colleagues have listed the advantages, disadvantages, and suitability of different simulation modalities (Table 7.2) in a well-conducted review [9]. Some advantages can make a simulator a favorable option for some. On the other hand, specific disadvantages could make an essential reason for the exclusion of a specific modality from a specific training program.

7.4.2 Modularity in Training

In the early steps of novice surgeon training, simple synthetic material, like a sponge, fulfills all the requirements (consistency, dimensions) of a surgical training tool, such as knot tying. One step forward is related to the models and the preset rules and goals provided for each task. To facilitate skill progression and standardization, the concept of modularity in hands-on training was recently introduced. This concept aims to define training pathways for every surgical procedure in a standardized, replicable manner and divides the surgical practice into basic, intermediate, and advanced tasks. A ***basic task*** is defined as a simple maneuver, like moving an object or cutting a gauze. An ***intermediate task*** includes a more complex maneuver that puts together different simple maneuvers, requiring complete mastery of basic tasks to be approached appropriately. Finally, an ***advanced task*** is the entire surgical procedure, composed of different procedural steps and complex maneuvers. One may easily understand that a trainee should gradually move from a simple to an advanced task. This modular pathway allows us to classify a synthetic material (sponge) as a *basic task* simulator, a pyeloplasty model as an *intermediate task* simulator, and cadavers and pigs as *advanced task* simulators. Regarding model composition, one may understand that moving up from "basic" to "advanced" often requires more details, thus a higher resemblance to the actual patient.

Table 7.2 Types of available simulator modalities (Modified and adapted from Aydin et al. [9])

Model	Advantage	Disadvantage	Ideal for
Synthetic model	Portable Reusable Minimal risks Use of real instruments Resemble discreate anatomical areas Low cost No safety or hygiene issues	Low-fidelity: acceptance by trainees poor face validity High-fidelity: cost Replicate part of the environment	Dependent upon fidelity: Low-fidelity best for part-task training High-fidelity best for procedural simulation
Animal tissue	Cost effective, Minimal set-up time	Special facilities needed for storage Single use Anatomical differences Smell Safety or hygiene issues	Basic surgical skills Part-task training
VR simulation	Reusable Data capture Physical interaction Objective performance evaluation Minimal set-up time Multidisciplinary Remote monitoring Full procedure	Cost, Maintenance, Down-time Lack of real instruments Poor 3D view Poor face validity	Basic skills and familiarization, Cognitive training
AR simulation	Reusable Data capture, Objective performance evaluation Minimal set-up time	Cost, Limited practice, Lack of real instruments	Procedural skills and familiarization Cognitive training
Live animals	High-fidelity, High face validity Full procedures	Cost Special facilities and personnel needed, Ethical concerns, Single use Anatomical differences	Advanced procedural knowledge Procedures in which blood flow is important Dissection skills
Human cadavers (fresh frozen, or Thiel-embalmed)	High-fidelity highest face validity of all models, full procedures	Cost Lack of physical signs Availability Single use Compliance of tissue Infection risk	Advanced procedural knowledge, dissection Continuing medical education

Table 7.2 (continued)

Model	Advantage	Disadvantage	Ideal for
Human patient simulator	Highest fidelity	Lack of objective metrics Cost	Communication and interpersonal skills
3D printed models	Patient-specific models Minimal risks Use of real instruments	Cost	Difficult cases
Full-immersion simulation	Cost effective Reusable Minimal set-up time Portability	Limited realism	Team training, Crisis management
High-fidelity operating room simulation	Reusable High psychological fidelity Data capture Interactivity Multi-professional application	Cost Maintenance Down-time Limited technical applications	Team training, Crisis management

7.4.3 Trainee Engagement

Choi et al. [177] have demonstrated a connection between simulation, fidelity, and realism and how this relevance can increase trainee engagement. The higher the engagement of trainees, the more opportunities they have for learning through simulation. Educators should find ways to boost trainee engagement creatively [178]. Universities and non-academical institutions usually differentiate the true meaning of hospital experience from that of simulation experience, a fact that minimizes the significance of simulation. A suggestion to improve the realism of simulated experiences would be to use similar terms like “on-campus clinical” and “off-campus clinical” to send a message to the trainees that simulation lab experiences are comparable to hospital experiences. Indeed, a well-designed simulation program can be more beneficial to the trainees as it can offer an experience they may not get in a natural clinical setting. Additionally, one thing that is lacking at a clinical site is common control by instruction. On the other hand, educators have complete control over the simulation, including the disease of a patient, complications, and different trainee assignments. Another factor that increases trainee engagement is the simulator’s realism or the simulator setting, and nurse educators and course coordinators should make every effort to ensure this high level of realism.

7.4.4 Increase Fidelity and Realism of the Simulator/Simulation

- Choose the type and level of fidelity that is more appropriate for a specific simulation and the appropriate scenario to maximize trainee learning.

- Pre-brief trainees.
- Give a few minutes for the trainees to plan as a team before starting the simulation.
- Give feedback and tips if the trainee is facing difficulties.
- Make it as natural as possible. Use instruments used in the actual setting.
- When possible, use sounds, smells, or visual stimuli.
- Try to help trainees learn the important training concepts and allow them to put those concepts into action.

Irrespective of the above parameters, it should be emphasized that a simulator itself is probably not that important, as there is a wide variety of others that would do a similar job. It is essential that the trainer chooses the suitable simulator for the right job and realizes that a simulator is simply a tool for delivering a training curriculum. For trainees, the curriculum, and not the simulator, is king. Most importantly, a simulation task's functionality is optimal if it allows the trainer to teach and train the required skills and assess the skills, he wishes the trainee to acquire.

7.5 Summary

There are a plethora of procedural training simulators that have also been applied in the field of Urology. These include synthetic, animal tissue, live animal, 3D printed models, VR and AR simulators, human cadavers, and full-immersion simulation. Fidelity, validity, and reliability are critical characteristics of simulators. To date, a perfect simulator does not exist, as advantages and disadvantages characterize all. Hence, several essential factors like training modularity, trainee engagement, ways to increase fidelity, and realism should be considered before establishing a simulation training program to select the most appropriate simulator/s according to the trainee needs.

Key Points

- Different simulator modalities include synthetic, animal tissue, live animal, 3D printed models, VR and AR simulators, human cadavers, and full-immersion simulation.
- Fidelity, validity, and reliability are key characteristics of simulators.
- Important additional parameters when choosing a simulator include costs, data capture, feedback, reusability, reproducibility, portability, health hazard, and requirement for special facilities or trained personnel.

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Chapter 8
Basic Laparoscopic Skills Training

Ben Van Cleynenbreugel

8.1 Introduction

The introduction of laparoscopy as a surgical tool in the treatment of patients was a surgical revolution. It also created a paradigm shift in the way surgical skills are taught to surgeons-to-be. No longer could students acquire the surgical craft by using patients as guinea pigs. Instead, the training was moved outside the operating room, to a training lab, which provides a safe, controlled, and stress-free environment. Initial courses focussed on specific laparoscopic tasks. This evolved over procedure-specific courses into proficiency-based progression training.

8.2 Main Body of the Chapter

8.2.1 History

In 1985, Erich Mühe performed the first laparoscopic cholecystectomy, after which laparoscopy as a treatment modality conquered the surgical world [1, 2]. The reason for this explosion in the number of laparoscopic procedures was not only the drive of doctors to profile themselves with a new surgical technique. Patients also applied strong pressure because they wanted to be treated with a surgical technique that promised less pain, smaller scars, and faster recovery with an equivalent result. Hospital managers and health insurers were also in favor of this new treatment

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modality because it created better bed occupancy rates. This generated more income and more than offset the purchase of necessary but expensive surgical equipment. Finally, the producers of this medical material also stimulated this new operating method for obvious reasons.

The rapid increase in laparoscopic procedures was associated with an increase in avoidable surgery-related complications, with iatrogenic lesions of the main bile duct (choledochus) being the most common [3]. This came to be known as "the laparoscopic cholecystectomy fiasco." An increase in the number of bile duct lesions was seen, with 90% of the lesions occurring during the first 30 operations—the learning curve—of the surgeon in question [4–7]. This translated into an increase in the number of malpractice claims. The explanation is that laparoscopic psychomotor skills (LPV) are fundamentally different from the skills required for open surgery, and surgeons in training were given less time to master those skills due to the working hours directive for trainee residents [8]. There were also ethical objections about teaching and learning surgical skills on patients, which was historically standard practice. Finally, national health care institutions and hospital management applied pressure to use the expensive available operating time as efficiently as possible and not "waste" it on time-consuming training. One minute of surgery costs 18 to 31 euros [9, 10]. This expensive operating time can increase up to 44 min by training a resident in the operating room [11, 12].

The factors above caused a paradigm shift in surgical training. Teaching surgical skills on patients in the operating theater, which has been the cornerstone of training for centuries, has now been shifted to training centers outside the operating room. Here, students can practice to acquire the necessary skills in a controlled, stress-free environment. Once this need to learn laparoscopic surgical skills outside the operating theater was evident, several laparoscopic training programs were developed. The emphasis was on acquiring the three basic laparoscopic skills: depth perception, bimanual dexterity, and efficiency. Several surgical sub-disciplines developed laparoscopic training programs, with two pioneers. The first was the Fundamentals of Laparoscopic Surgery, developed in 1997 by the Society of American Gastrointestinal and Endoscopic Surgeons [13]. The second was the Gynecological Endoscopic Surgical Education and Assessment program, developed by the European Society for Gynaecological Endoscopy in collaboration with the European Board and College of Obstetrics and Gynaecology [14]. The latter program contains three proficiency levels, tests the participant's theoretical knowledge, and trains both endo- and laparoscopic skills. In urology, the European Basic Laparoscopic Urological Skills (E-BLUS) was rolled out in 2012 [15, 16].

8.2.2 Basic Laparoscopic Skills (BLS)

Laparoscopy differs fundamentally from open surgery. Specifically, the surgeon's hands are no longer in the operating field, but manipulate long instruments outside the patient's body. The surgeon no longer looks directly at the operating field, but at a monitor on which the operation is displayed. The instruments used are long and are introduced into the patient's body via trocars. This creates a fulcrum effect. This requires surgeons to adjust to the discrepancy between the visual and proprioceptive information they are receiving. In addition, they receive little tactile feedback, and the instruments used are less mobile than the human hand. Finally, the operation is displayed on a 2D screen, which makes spatial orientation and correct positioning of the instruments in the operating field difficult [17, 18].

8.2.3 E-BLUS

E-BLUS is performed with a fixed camera position in a laparoscopic box trainer. This exam consists of four laparoscopic exercises:

1. The first task is a peg transfer. The student picks up six plastic cones with a laparoscopic grasper, transfers them to the laparoscopic clamp in the other hand, places them on a peg board, and reverses the process. The tester counts the number of cones dropped, which is scored as an error. The target time to complete this exercise is 126 s. The test requires two laparoscopic graspers.
2. Pattern cutting. The student cuts a circle between two pre-marked lines on a compress. The tester scores a cut through the outer or inner line of the marked circle as an error. The target time is 181 s. This task requires a dissector and scissors.
3. Single knot tying, wherein the student makes an intracorporeal knot on a Penrose drain. Errors are a needle insertion or exit point more than 1 mm away from the marked black dots, non-approximation of both sides of the opening made in the Penrose drain, and a slipping knot. The target time is 360 s. This task requires two needle drivers.
4. Needle guidance. The student guides a needle on a fixed route through ten metal rings of varying diameter and orientation. The target time is 268 s. This task requires two needle drivers.

Before the start of each exercise, students have 1 min of practice time. They can repeat each exercise once but cannot move on to the next exercise until they passed the first one. To pass the exam, they have to pass all exercises, with only one repeat allowed. Testers score all these tasks on quality and time. In addition, the participants complete a questionnaire assessing previous training and laparoscopic experience. Finally, experts score all participants on a global assessment scale. The three basic laparoscopic skills (depth perception, bimanual dexterity, and efficiency) are rated on a Likert scale, where the score can vary from a minimum of one to a maximum of five.

8.2.4 Is There Still a Need to Train Basic Laparoscopic Skills in 2022?

Despite the long history of training laparoscopic skills, there is still a need for laparoscopic training in 2022.

Carrion et al. conducted a survey among 350 European residents. Only 14% feel their training prepared them adequately to perform solo surgery and 83% would like to continue training with a fellowship [19]. This is in line with other data from Italy, Spain, and Germany [20–22]. Oliveira et al. reviewed laparoscopic training in urology training programs (Table 8.1) [23–30]. They concluded that there is a wide

Table 8.1 Summary of published laparoscopic training in urology residency programs modified and adapted from [31]

References	Country	Number of participants	Exposure to laparoscopy during the residency	Experience in laparoscopy during the residency	Future expectations on laparoscopy	Comments
Lavi et al. [23]	Israel	61		Low degree of confidence in independently performing laparoscopic procedure		Slight improvement in confidence in the final year of residency
Linden-Castro et al. [24]	Mexico	98		13% consider laparoscopy training adequate		77% consider laparoscopic training should be improved
Aydin et al. [25]	UK	91		Most residents disagreed or strongly disagreed on the sufficiency of their training to develop technical skills in laparoscopic surgery		Specialist opinion on the sufficiency of urological training to develop techniques. 1 was more favorable overall, but was comparable when only laparoscopy was considered
De Win et al. [26]	Belgium	52		26.9% felt able to perform laparoscopy at the end of the residency	88% felt they would need an extra laparoscopy fellowship	

Table 8.1 (continued)

References	Country	Number of participants	Exposure to laparoscopy during the residency	Experience in laparoscopy during the residency	Future expectations on laparoscopy	Comments
Garde Garcia et al. [27]	Spain	36	Radical nephrectomy (84% as assistant, 36% as surgeon), radical prostatectomy (75% as assistant, 24% as surgeon)	58.3% consider their training inappropriate	Partial nephrectomy (42% do not expect to do in the future), radical prostatectomy (34% expect to do in the future)	86.1% believe training could be improved, of which 58.1% with external rotations and fellowships
Furriel et al. [28]	European Union	219	25% no access, 43% as assistant, 27% as surgeon	16% satisfactory, 7% good, 1% very good	28% satisfactory, 15% good, 8% very good	
Preston et al. [29]	Canada	56	85% in centers that perform >50/year	67% with good or extensive experience	98.2% plan to perform in the future	Final year residents
Duchene et al. [30]	USA	372	47% in centers that perform >100/year	18% average, 14% good, 8% extensive	88% believe they will perform laparoscopic radical nephrectomy in the future	53% of directors consider their programs at least average, compared to 38% of residents

variation between exposures to laparoscopy among different programs. Despite that, most residents would prefer higher exposure to laparoscopy throughout their residencies [31].

These findings are in line with a survey carried out in 2020 among 225 Brazilian urological residents [32]. Results from the questionnaire revealed that 42.1% had no laparoscopic training during residence. The same results materialized in a survey on laparoscopic training in Belgium [26]. Only 28.8% of gynecology respondents, 26.9% of urology respondents, and 52.2% of general surgery respondents felt they would be able to perform laparoscopy once they had finished their training.

8.2.5 When Should We Train?

This should be done as soon as possible in the trainee's career. Several authors have suggested that the likelihood of performing laparoscopic procedures as a urologist is related to the experience in laparoscopy during residency. The study by Shay et al. with a survey performed by a series of American urologists who completed their residency over a 20-year period demonstrated that while 69% of urologists trained in laparoscopy during their residencies continue to perform these procedures, only 34% of urologists who had not been trained during residency perform laparoscopic procedures ($p < 0.025$) [33]. The authors concluded that laparoscopic procedures in urology are more likely to be performed by physicians who have received training during residency. In line with these results, the study by Abdelshehid et al. demonstrated a strong statistical correlation between the performance of laparoscopy as a primary surgeon and laparoscopic training during residency [34]. This was done through a survey, answered by American Urological Association-registered practicing urologists.

8.2.6 Where Should We Train?

The operating room is a stressful environment. Specific operating room related stressors are the complexity of the task at hand, technical challenge, surgical complications, time pressure, a high-risk patient, the need for multitasking, and poor assistance [35]. The psychological reactions to stress, and coping with it, were first described by Cannon ("fight or flight" response) and Selye [36, 37]. Psychophysiological research shows that high levels of biochemical stress markers affect cognitive processes [38, 39]. Research in sports, aviation, and the military identified stress as a negative factor on professional performance [40–44].

The amount of (perceived) stress, stress response, and coping mechanisms influence the surgical performance and outcomes [44]. It also compromises surgical performance during simulations, as shown by Wetzel et al. [45]. In their study, 30 surgeons each carried out a non-crisis and a crisis scenario of a simulated operation. Surgeons' stress levels were assessed by several measures: self-assessments and observer ratings of stress, heart rate, heart rate variability, and salivary cortisol. The result indicated that stress and coping skills are important factors for the outcome of surgery when dealing with challenges of advanced procedures, independent of surgical experience.

Studies on laparoscopic tasks (e.g., a laparoscopic transfer task) have shown deteriorated performance under experimental conditions such as noise, sleep deprivation, and time pressure [46–48].

Therefore, it does not come as a surprise that (laparoscopic) surgical skills are best trained outside the operating room in a quiet and stress-free environment.

Equally important is the feedback quality trainee receives. Individualized feedback during simulated laparoscopic training improves performance [49]. Even when using a virtual reality simulator, which generates performance reports, there is a clear advantage to using individualized feedback [50]. Even "simple" motion parameter feedback is superior to no feedback at all [51].

8.2.7 Is Training Useful?

In other words, are the skills learned in the lab transferable to the operating room? The simple answer is yes. Sleiman et al. proved that basic hysteroscopic skills, acquired in the lab, result in a better perioperative orientation and performing of a hysteroscopic punch biopsy in a group of 39 gynecologists without previous experience or training [52]. De Win et al. demonstrated a reduced risk of adverse events and a more efficient operation when performing a laparoscopic cholecystectomy in patient after following a simulation-based training (n = 30 final year students) [53]. These and other studies prove the transfer of skill from the lab to the operating room [54].

8.2.8 Different Training Models for BLS

Several different simulators are available for training basic laparoscopic skills [55]. Bench-top models have been around since 1986. They are usually inexpensive, easy, and intuitive to use; can be used unsupervised at any given time; and do not require a special setup. Residents gain familiarity with the same type of equipment they will be using in the operating room. Bench-top models consist of a training box, laparoscopic instruments, a camera, and a light source. It can be homemade, using a high-definition webcam, plastic storage box, and fluorescent light source. An alternative for a webcam and laptop or desktop is a smartphone or tablet that further reduces the costs. Construct validity and skill acquisition with this type of portable, personal laparoscopic trainer have been proven [56].

Apart from these so-called low-fidelity models, which bear little resemblance to actual human anatomy, high-fidelity models aim to replicate human anatomy and tissue as closely as possible. It is not unequivocally clear whether model fidelity is a crucial factor in skills acquisition. Most studies show low- and high-fidelity models to be equivalent, with both levels of fidelity outperforming traditional didactic teaching [57, 58]. The crucial part is that bench models replicate critical steps of a given procedure. Some studies, though, suggest that high-fidelity models are better to teach complex procedures, like vascular anastomosis [59]. As a consequence, high-fidelity models benefit experienced surgeons when they want to start with more complex procedures.

Another type of laparoscopic surgical simulation trainer is the virtual reality trainer. These exist as partial task trainers that emphasize psychomotor skill acquisition, or as both partial task and full-procedure trainers. They are expensive and require maintenance and specialized personnel when they malfunction or crash. On the upside, they are adaptable to the trainee's skill level and automatically record and track the trainee's performance and compare it with that of others. Performance parameters measured with virtual reality training have proven to correlate strongly with operating room performance [60, 61]. Furthermore, several randomized controlled trials have investigated whether skills learned on a virtual reality trainer transfer to improved operative performance, which is the case [62–64]. Both low-fidelity bench models and virtual reality models result in improvement of operative performance [65]. Nevertheless, there is conflicting data on whether one of the two is superior to the other [66].

8.3 Summary

Simulation-based training improves operating room performance. Surgical trainees should receive it as soon as possible in their education. An ultra-realistic simulator or animal or human cadaver training is not necessary to learn BLS. With the help of a computer, tablet, or smartphone, the trainee can build a homemade laparoscopic trainer. This reduces the cost of SBT significantly and makes this type of training more accessible.

Key Points

- Simulation-based training improves operating room performance. Surgical trainees should receive it as soon as possible in their education.
- An ultra-realistic simulator or animal or human cadaver training is not necessary to learn BLS. With the help of a computer, tablet, or smartphone, the trainee can build a homemade laparoscopic trainer. This reduces the cost of SBT significantly and makes this type of training more accessible.

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Chapter 9
Intermediate and Advanced Training in Laparoscopy

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Abbreviations

AUA	American Urological Association
CTA	Cognitive task analysis
EAU	European Association of Urology
E-BLUS	European basic laparoscopic urological skills
EERPE	Endoscopic extraperitoneal radical prostatectomy
ESU	European School of Urology
EUREP	European Urology Residents Education Programme
FLS	Fundamentals of laparoscopic surgery
RARP	Robot-assisted radical prostatectomy
SISE	Standardization in surgical education

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9.1 Introduction

Surgical education is a field that most people are not fully aware of. If you ask a patient about how their doctor was prepared for this lifetime mission, they probably never really thought about it. But when they start realizing that a proper training is required, even just to reach the minimum competency required to manage an operation on a human being, then they usually start to feel apprehensive. Being scared is probably the feeling they have while undergoing surgery by a professional who is in their early learning curve, which is absolutely understandable.

Learning curves are natural for any practical task, from the easiest to the most complex one. It is normal to fall from the bicycle during the first trials, just like it is easy to predict that you will fail on the preliminary attempts of any novel activity that you undertake. Albert Einstein said that “A person who never made a mistake never tried anything new,” but despite the words of a genius, mistakes are not, and should not, be always allowed, especially when it comes to high-stake jobs. The concerns that arose from such considerations have driven to a new ground of research about education, which involved the field of military previously and the medical training lately. While simulators (sims) are a regular part of the educational pathway for war pilots since the early 30s, medical sims started to become a reality around 1950, when defibrillator models and mannequins for resuscitation made their appearance [1].

The so-called hands-on training, meaning *learning by physically touching under supervision*, became a reality in Urology since the mid-90s [2–4], with the adoption of the first educational protocols by a few academic centers in the world. By that time, the need for surgical education was guided by the introduction of novel technologies, such as laparoscopy and training were delivered in centers by mentors who were early surgical pioneers. Between 2006 and 2010, simulation training underwent a preliminary standardization, thanks to the adaptation of the Fundamentals of Laparoscopic Surgery (FLS) [5] in Urology by Brinkman et al. [6]. The newborn E-BLUS (European Basic Laparoscopic Urological Skills) protocol was delivered for the first time in Prague during the European Urology Residents Education Programme (EUREP), flagship course of the European School of Urology (ESU), with incredible success. The protocol was easy to replicate, required just five instruments on the table with a simple box trainer and a laparoscopic tower, with four training plates that were extremely portable. Moreover, the protocol used synthetic tools, thereby avoiding the need for animal or cadaveric models. This format allowed the widespread popularity of basic laparoscopic skills to over 40 countries [7] until 2019 and suggested the need for a structured system that could lead a trainee to the completion of a full surgical procedure. E-BLUS has indeed included just simple maneuvers and is not comprehensive enough to allow the acquisition of procedural-specific skills, which led to some critics regarding its lack of predictive validity evidence [8]. For this reason, in 2016, the ESU training and research group integrated this protocol as part of a broader *modular hands-on training system* [9], where E-BLUS was considered as the first of a 3-step pathway including basic skills, complex tasks, and full procedures, formally basic, intermediate, and advanced surgical training. The depiction of this system allowed the development of other similar protocols, which is today the basis of modern initiatives like the SISE (Standardization In Surgical Education) program by the European Association of Urology (EAU), aimed to standardize and spread the educational standards on a global scale.

9.2 From Theory to Practice: The Development of a Novel Protocol

In order to develop a new protocol with solid scientific evidence, it is critical to follow strict methodological steps. Between different possible methodologies available in the literature, the full life-cycle curriculum development by Satava and Gallagher [10] was derived by the ASSET (Alliance of Surgical Specialties in Education and Training) consensus as described by Zevin et al. [11]. The template (Fig. 9.1) includes several steps that need to be followed in order to complete the process correctly:

1. As depicted by the template, the process starts with the definition of outcomes and metrics. This is usually done in collaboration with scientific societies, credentialing boards, or in general the entity that is commissioning the protocol.

WHAT	Outcomes & Metrics	Curriculum development	Simulator development	Validation studies	Implement Survey Training Certification	Issue Certification
HOW	Consensus Conference	Standard curriculum template	Engineering physical simulator	Standard validation template	Current procedures	Issue Mandates and Certificates
EST s1	Nov 2014 YAUWP CTA Feb 2015 ESUT meeting Davos	Apr 2015 cognitive/HoT development Sept 2015 preliminary test EUREP15 Feb 2016 EULIS consensus	Mar 2016 simulator review Jun 2016 simulator adaptation Jun 2016 simulator test ESUT16	Sept 2016 validation EUREP16 Dec 2016 EULIS consensus	Mar 2017 final tests EAU17 2017 ART in flexible	Sept 2017 first exams EUREP15

Fig. 9.1 Full life-cycle curriculum development example, from the EST-s1 development process

This phase can be directly run by a Delphi consensus between experts and is better anticipated by a deconstruction of the procedural requirement. The process is called Cognitive Task Analysis [12] (CTA) and can be run by interviewing one or more expert surgeons about the details of the task. A well-structured CTA includes indications, contraindications, equipment needed, pre-procedural setup, patient positioning and anesthesia, procedural steps, do's and don'ts, error prevention strategies, and handling of complications. The expert(s) involved will provide answers that are aligned with the current best practice and guidelines while providing information about the cognitive process that sits behind any single maneuver. All collected data are analyzed afterwards and used to derive the preliminary metrics.

2. After having defined the outcomes and metrics, CTA is then used to develop the tentative list of tasks, cognitive contents for theoretical material along with the practical curriculum. Non-technical skills addendum might be elaborated in this phase as well. Once the preliminary curriculum has been defined, Delphi method [13] is applied to reach a consensus between the experts and under the umbrella of the commissioning entity with regard to its details and applicability. Curriculum development also allows to define the simulator requirements, which is critical to move on to the next phase.
3. In the simulator development phase, requirements set are used to select the most suitable armamentarium to put these tasks into practice. Starting from a review of the existing simulator is a good way to shorten this process, as a product that has already been commercialized. It might fit the needs of the protocol or be adapted to it with slight modifications. In case no existing simulator meets this requirement, dedicated development of this needs to be undertaken with the involvement of engineers, artists, clinicians, and psychometricians. This process should also consider the demand that will be needed once the prototype is completed. Apart from being developed in strict accordance with the metrics that needs to be assessed, and the overall requirements of the curriculum, it should be appropriate and be balanced with the end-user. The final cost, applicability, and availability of the product will indeed define its adoption and widespread usage. This aspect will be critical to contribute to the success of the protocol itself.
4. Validation is the step that follows development, confirming its quality and efficacy. In case the simulator is purpose-built and follows the set requirements, validation will relate not only to the contents and metrics but will depend on the ability of the simulator to assess these parameters. The five validity factors include face, content, criterion, construct, and predictive [8] validity, which are usually considered as the standards which need to be met.

   Face validity defines whether the simulator correctly replicates the real corresponding task.

   Content validity evaluates the knowledge and metrics background.

   Criterion (or Concurrent) validity compares the curriculum to the gold standard in the field.

   Construct validity defines whether the curriculum is able to discern experts from novices.

Predictive validity predicts the transferability of training to the real surgical field.

Recent studies tend to focus mostly on content validity, construct validity, and assessment methodologies used. An example is provided by Messick's framework of validity [14] applied to the surgical field [15, 16]. Test content, response processes, internal structure, relationship to other variables, and consequences of testing are the new validation variables proposed by Goldenberg [17], which consider mostly the objective ability of the simulator to measure the initially proposed outcomes, rather than on its face value. This change of perspective is already impacting the development of novel training protocols and simulators, with a major push on the metrics.

5. Once the value of the curriculum has been confirmed by scientific evidence, it is time to test its feasibility with the final aim of issuing a certification to the participants. In this phase, the teaching modalities are optimized to avoid negative training and to put the accent on errors. The trainee needs indeed to understand when an error occurs and how to avoid it with formative feedback from the tutor. They are guided from the easiest to the most difficult task of the protocol. This allows them to improve their skills and finally reach proficiency, thus following the *proficiency-based progression* method described by Gallagher and colleagues [18]. To test the transferability of skills, each trainee should undergo a baseline test and a post-completion test on the same simulator (usually different from the one just developed but focused on similar skills), ideally using the objective performance improvement methodologies. The Pi-score [19] is one of those tests and allows to measure the performance improvement with an objective score from one trial to the next while taking into account the number of errors and time to complete this task. In consideration of its pure algorithmic nature, its calculations strictly depend on the metrics elaborated in the development phases and its efficacy needs to be tested independently, for every single curriculum [20].
6. The last phase of the development is to certify the skills achieved by following all the tasks. In order to close the *development cycle*, the certification issued has to confirm the achievement of each goal, which is selected as an *outcome* at the beginning of the process. Learners should get the certification just after finishing the post-training test or examination with no errors, and performance aligned with the one shown by the experts.

9.3 Intermediate Training and Complex Tasks

Intermediate training is considered as an educational process that a surgeon needs to follow in order to achieve proficiency on complex surgical tasks. Complex tasks are defined as the most challenging steps of a full procedure [9], and proficiency in basic skills is suggested for a stepwise approach to them. Complex tasks usually require higher fidelity models and are more specialty-specific compared to basic skills. Intermediate training is not yet as standardized as basic training, especially due to the higher effort required to develop evidence-based and measurable tasks that may include several variables. The development of objective metrics becomes indeed increasingly complicated as the tasks move from basic to advanced. In order to provide a clear understanding of what is available to date, intermediate training protocols and available simulators will be described in relation to the different surgical domains.

9.4 Laparoscopy and Robotics

In 2015, the ESU training and research group distributed a survey among 30 experts, asking them the skills/steps needed to be trained before approaching the first complete laparoscopic procedure. In order to reach a consensus, 19 different complex tasks were presented, pertaining to trocar placement, mobilization/identification/dissection of tissues, suturing, and hemostasis. According to the survey, the participants needed to classify every single task as "not important," "advisable," or "critical" to train upfront. As a final result, these complex tasks selected by the experts were:

– Dismembered pyeloplasty
– Vesicouretral anastomosis
– Major vessel injury repair
– Partial nephrectomy
– Hilum dissection

A similar list was elaborated by the AUA Laparoscopic, Robotic and New Surgical Technology (LRNST) committee, including:

– Pyeloplasty
– Y-V plasty
– Vesicourethral anastomosis
– Control of aortic and inferior vena cava injury

While none of the two scientific societies has yet published a feasible training protocol for intermediate surgical training, the work is in progress for completion of the CTA regarding the five complex tasks identified by the European School of Urology. As previously described, CTA is the first step of a long process and is intended to allow the elaboration of outcomes and metrics for each task. Despite the lack of official guidelines, some simulators are already available to replicate the aforementioned tasks, even though only a few have undergone a validation following the recommended criteria.

In 2005, the Heilbronn laparoscopic training program [21] included some of the tasks including providing standardized step-by-step guidance on organic models. While until 2013, organic materials were still in use for pyeloplasty training [22, 23],

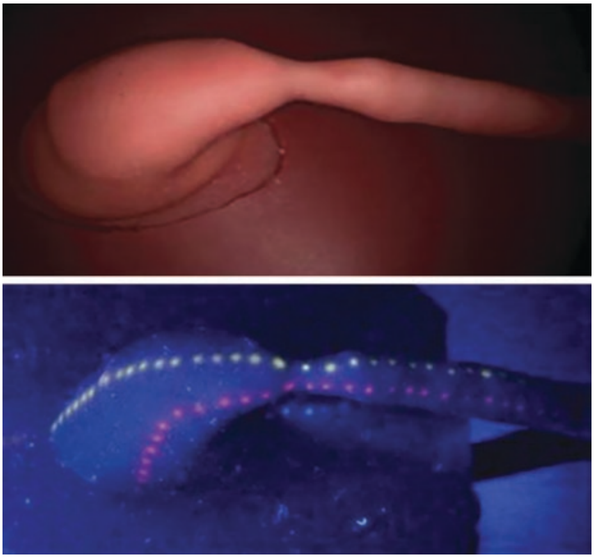

Fig. 9.2 BLAST markers on pyeloplasty model

in the same year Poniatowski et al. [24] described the development and validation of a *pyeloplasty* model, created using organosilicate-based materials and cast using a patient-specific 3D printed mold. A special addition to the model was the Black Light Assessment of Surgical Technique (BLAST), based on UV sensitive markers (Fig. 9.2) to track the correct alignment of the anastomosis. The markers were not visible under room or endoscopic lights. The study involved 31 participants and showed preliminary evidence of face, content, and construct validity. Three-dimensional printing offered clear advantages for the development of newly designed models [25, 26], which led to other attempts described in the literature for robot-assisted laparoscopy training [27–29]. Homemade models have also been tested for face validity [30], with remarkable advantages regarding cost, but low scores for efficient metrics assessment.

Vesicourethral anastomosis (VUA) has been one of the most attractive tasks to simulate since the beginning of the laparoscopic era. Early models were based on chicken organs, rearranged to mimic human structures. In 2003, Katz [31] described a model made of a 5 × 4 cm skin patch fashioned into a 4 cm tube over a 16 Fr catheter, to be anastomosed with another piece folded to mimic the bladder. Apart from using skin [32], other authors [33, 34] reported the adaptation of chicken parts, sometimes together with porcine organs [35], to efficiently train these specific skills. Porcine parts were still the most popular [36–38] when few studies began to describe synthetic models. In 2009, Sabbagh et al. [39] published a comparison study between a latex VUA task-specific model versus simple stitching on foam pads, with clear advantages in learning for the first group as confirmed by the procedural test on anesthetized pigs. Similar concepts of training on synthetic models were described thereafter with satisfactory results [40, 41].

Fig. 9.3 Major Vessel Injury repair model (INTECH)

Major vessel injury repair was studied for task-specific training by Veneziano et al. in 2016 [42] (Fig. 9.3). In the manuscript, the authors tested a silicon-based model with 17 residents enrolled and a pre-determined scenario with some interaction with the anesthesiologist to avoid the maximum allowed synthetic-blood loss of 3 L. This study was a preliminary analysis of major vessel repair.

In the literature, we can find a few examples of partial nephrectomy training, especially due to the very specific anatomic setting needed. An actual renal tumor is indeed rare to be found either on cadaveric or animal models; therefore, in 2004, Taylor et al. [43] described a model that consisted of a heated liquid mixture of agars, cellulose, and glycerol to be injected inside a porcine kidney to mimic endophytic lesions. While in 2009, Yang et al. [44] suggested the simple excision of a kidney portion to simulate a partial nephrectomy, Hung in 2012 described the development of a foam sphere to be superglued to a porcine kidney after the rapid excision of a parenchymal portion with a melon scooper. An evolution of this approach was presented in 2017 by Isotani [45], who described the development of a fully synthetic kidney with polyvinyl alcohol, using 3D printed data derived from an actual patient. Ultrasonic and energy devices could be successfully used on the model, also making it fit for robot-assisted training. Similar approaches were described by Maddox [46] and afterwards by Ahmed [47], who described the use of hydrogel casting to create patient-specific rehearsal platforms for robotic-assisted partial nephrectomies. The possibility to compare the replica with the correspondent real procedure added even more relevance from an educational point of view.

While no specific task was developed for hilum dissection, ureteral anastomosis for ureteroneocystostomy was simulated and validated in 2013, using low-cost materials [48].

It is relevant to mention that all the studies reported for intermediate laparoscopic and robotic training were aimed to describe novel models or training approaches, along with a validation process that was strictly related to the skills involved, but with very few details regarding the development process. As previously mentioned, in order to develop a comprehensive simulation, it is necessary to define the relative metrics following a well-described methodology, which in the aforementioned studies was often not followed, thus determining an overall lower value of the training protocols.

9.5 Advanced Training and Full Procedures

Advanced training, the educational process that involves the acquisition of skills related to full procedures, is probably the oldest and most difficult to apply. Teaching how to perform a procedure was indeed historically left to observing an expert and then performing below their mentorship. This happened in accordance with their personal experience and background in a non-standardized fashion. Being lucky enough to encounter a real expert as a mentor and finding the right ecosystem to have some freedom at the operative table was the only way to become a good surgeon. The standardization process brought to finally discern the basics from the complex and complete tasks allowed an easier comprehension of the learning process. Today completing the first full procedure has become more like a guided pathway rather than a matter of luck, with clear advantages on patient safety. In the era of standardized teaching, advanced training has been shaped by several studies, which let us understand why a cadaver may not be the best training platform to deliver surgical training and why detailed "rules" to guide the training activities are needed. As explained before, metrics and their assessment are between the core characteristics of modern simulation. In relation to this, it is worth mentioning that cadavers were already used as the first testing platform by automotive industries, for the development of safety measures on early car models. Unfortunately, neither cadavers, animals nor fighter pilots were good enough to reach the final goal: providing objective data collection after an accident, in a replicable manner. This is what guided the adoption of the first Hybrid III in 1976, a crash test dummy that was filled up with sensors and ready to upfront the worst car accidents. Once again, the requirements set by research shaped the new systems [49]. In accordance with the latest updates in surgical training, different methodologies have been followed to collect data, create standardized environments, and update platforms to make them more reliable, even when it comes to the *old* cadaver. In absence of standardized protocols for full advanced training, we will focus on this part on the available full procedural simulators and methodologies.

9.6 Patient

Mentored surgery on a patient is definitely the most debated, but also a popular way to prepare new surgeons. What is today seen as the *old-school*, was used to form the shape and mentor thousands of surgeons, sometimes by following well-planned strategies.

In the early days of laparoscopy inventions like the Laptent [50] allowed open surgeons to experiment with the revolutionary endoscopic abdominal approach, while still remaining within the borders of surgical safety. In 2006, Stolzenburg et al. [51] divided the Endoscopic Extraperitoneal Radical Prostatectomy (EERPE) into 12 segments and five levels of difficulty. It was a modular strategy that allowed the trainee to approach and progress through different levels after having completed the previous one, always under supervision. In 2016 [52], a multi-institutional study was run to develop and validate a modular training and assessment pathway for trainees undertaking Robot-Assisted Radical Prostatectomy (RARP). In this case, over 42 console hours from five surgeons were observed, with the identification of 17 stages and 41 steps in the procedure. Afterwards, the methodology developed was tested over 15 novices performing a total of 426 cases, with full tracking of their progression along the learning curve. A similar goal was pursued in 2018, with in vivo modular training over 40 surgical steps elaborated in relation to RARP [53]. In all cases, despite the possible ethical considerations derived by training activities run on a patient, the reported results derived by a standardized modular methodology were satisfactory, with a relative increase in patient safety.

9.7 Cadaveric Models

For a long time considered as the best training model, cadaver training is still one of the most popular platforms for advanced surgical education. Its anatomical properties are almost impossible to be fully replicated by other organic or synthetic systems, making it an irreplaceable tool for anatomic dissection since the beginning of medicine. A cadaveric advanced course is, however, limited by costs and facility requirements. Also, one cadaveric course might be completely different from another one, not only in relation to the teaching methodology used but for the different preservation modalities applied. *Fresh cadavers*, the human cadavers that are not chemically treated, are sporadically used for training, due to their low availability. The possibility to store cadavers and use them whenever needed is provided by the implementation of embalming techniques, with the injection of different chemicals. *Hard fixation*, the oldest methodology [54, 55], allows to preserve cadaveric structures with less joint flexibility. Due to this characteristic, this prepping methodology which is often based on the use of Formaldehyde or Genelyn (Genelyn Pty. Ltd., Australia) has been replaced subsequently by *Soft preservation*, especially for surgical training. Walter Thiel pioneered this technique over 20 years ago [56], with results that were close to fresh cadaver physical properties. Thiel embalming technique is expensive and uses chemicals that are very flammable and dangerous to handle [57]. Soft cadaveric tissues can be achieved today also thanks to the Nova Medical School technique, described by O'Neill et al. [58] in 2013. The infusion of this embalming solution shows no increase in skin resistance, live-like coloration, and movable joints for a period of up to 1 year, allowing great usability for advanced surgical training.

9.8 Animal Models

Just like cadavers, animals have also been largely used for full procedural training and are one of the most popular platforms. Lab animals were initially used not only to train novices but also to experiment and improve existing techniques. Thanks to similarities with the human anatomy, some settings like the geometry of laparoscopic suturing [59] and early robotic telementoring/telesurgery experiments were run on the swine [60], with a second console operated from distances between 1300 and 2400 miles. Hisano et al. described in 2013 [61] the use of a porcine model for laparoscopic radical nephrectomies, concluding that it was feasible for teaching and practicing retroperitoneoscopy. It is interesting to mention that weekly laparoscopic training produced approximately 45% reduction in the blood lost on regular surgical procedures and 35% improvement of depth perception, but no improvements in the total operative time, showing the importance of advanced training for patient safety, even for surgeons with previous experience [62].

A porcine model was also successfully used for robotic-assisted surgical training, either on new platforms [63] or for acquiring confidence with complex procedures like kidney transplant [64]. Despite the expensive process of growing up lab animals in a controlled environment and the need for dedicated facilities, this platform is still one of the most efficient methods for living simulation of full surgical procedures.

9.9 Virtual Reality

Virtual Reality (VR) is today a platform with the highest potential for training (see Chap. 25 for more details). Thanks to the exponential growth of technology, it is predictable that computational power will increase with a contemporary decrease in the price of technological equipment, thus allowing a widespread adoption of this simulation methodology. While VR is already well established in the entertainment field, it is not yet fully ready for basic [65] or an advanced range of surgical training. The use of VR has been reported as a warm-up for laparoscopic training [66], but it is mostly in robot-assisted surgery that it has been studied for possible applications. This is possibly connected to a lack of ability in providing proper force feedback, which is a critical need for laparoscopy, but not relevant when the interaction is limited to the surgical console. Ebbing et al. [67] described the development of a full procedural robotic-assisted radical prostatectomy simulator in collaboration with Simbionix (Simbionix Ltd., Beit Golan, Israel, now 3D Systems). The authors provided face, content, and construct validity evidence for non-guided bladder-neck

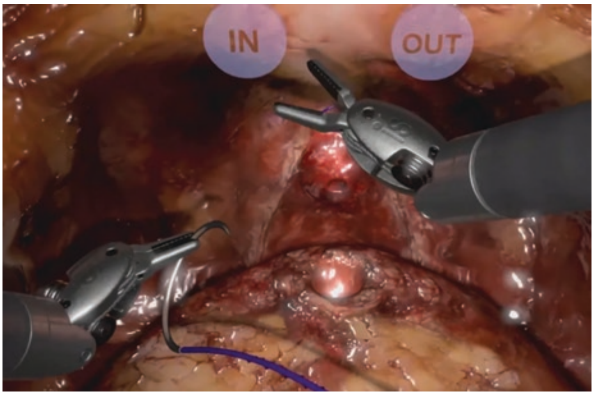

Fig. 9.4 VU anastomosis module from RobotiX Mentor™ (Simbionix)

(Fig. 9.4) and neurovascular-bundle dissection modules. A study by Raison et al. [68] demonstrated higher efficacy of procedural VR tasks vs basic tasks in the transfer of skills over a fresh cadaveric model. The assessment was performed using GEARS scores and concluded that further work should be put into more advanced surgical skills training. Virtual Reality is still a technology that needs time to become mature in the surgical simulation field. At the current stage of development, it seems very promising for its reusability and assessment capabilities, even if a relevant market growth will be necessary to bring down the costs for its widespread use.

9.10 Advanced Training Protocols

"The simulator is just a tool," said Richard Satava, one of the fathers of modern simulation training. Indeed, the *rules of the game*, the protocols, now define how the simulator needs to be used and which metrics need to be measured. Protocols for full procedural training have been developed during the last decade, providing instructions on how to successfully achieve proficiency on a procedure, starting almost from scratch. The importance of metrics started to be underlined in 2012 by Gallagher [18, 69], who explained that these were critical to establishing benchmarks for training progression. Later on, in 2015, Satava et al. [10] published the previously described full life-cycle curriculum development methodology, based on nearly 100 years of technical skills simulation in other high-risk sectors, to allow easier development of proficiency-based progression protocols. The template was preliminarily adopted for the development of the Fundamentals of Robotic Surgery (FRS) and then followed in other protocols like the EST-s1 [70]. A structured training pathway for the acquisition of RARP skills was presented by Lovegrove [52], based on Healthcare Failure Mode and Effect Analysis (HFMEA), who showed by learning curve analysis the experience needed to reach a level of competence in technical skills to protect patients.

Similar protocols, despite being able to provide critical learning in advanced skills acquisition, require dedicated environments, high surgical volumes, and availability of highly equipped simulation facilities [71], which may negatively impact the democratization of education. Although standardization seems the only way to gather information correctly, every individual has different abilities, and this should be kept in mind to ultimately maximize his/her learning curve. Probably, after a decade spent on standardization, the next step could be the adaptation of standards to trainees, and there is where understanding the importance of *perception* becomes critical.

9.11 The Role of Perception

Human perception of information about the surrounding environment contained in visible light (which is sometimes referred to as "eyesight," "sight," or "vision") is facilitated by multiple physiological components in the human visual system. These include different levels of senses among sexes that provide sensory inputs and the cognitive interpretation of these sensory inputs from the brain. For example, the basic framework of the journal report-studies within Biology of Sex Difference [72] shares a synthetic phrase: "*females are better at discriminating among colors, researchers say, while males excel at tracking fast-moving objects and discerning detail from a distance, evolutionary adaptations possibly linked to our hunter-gatherer past*."

Visual perception is defined as the mental organization and interpretation of visual sensory information, with the intent of attaining awareness and understanding of the local environment (e.g., objects and events).

Cognition refers to the human-like processing of information and application of previously acquired knowledge (i.e., memory) to build understanding and initiate responses. Cognition involves attention, expectation, learning, memory, language, and problem-solving.

The direct physical stimuli for visual perception are the emitted or reflected quanta of light energy from objects in the visual environment that enters the eyes. It is important to understand that the resulting perception of the stimuli is not only a result of their physical properties (e.g., wavelength, intensity, and hue) but also of the changes induced by the transduction, filtering, and transformation of the physical input on the entire human visual system.

Information shared from the view in one eye to the other eye is known as crosstalk, which as a rule severely damages the quality of the perceived image but can also affect the fusion of the two images. At this crosstalk, the fusion is limited by 27 min/s of arc (arcmin) for crossed disparity and by 24 arcmins for the uncrossed disparity. For a 200 milliseconds (ms) stimulus, crosstalk has only a small effect on fusion, which is no longer true for a 2-second stimulus. In this case, crosstalk can already hamper fusion and can cause cognitive distortion.

Surgery induces high-level cognitive factors, such as immersive autostereoscopy to create real-world scenes with a variety of cues to depth and distance. These cues include binocular disparity, focusing on depth by accommodation, motion parallax, and linear perspective. For ease of viewing, all these cognitive factors are supposed to provide the same magnitude of depth, otherwise, the viewer experiences high-level cue conflict. Cue conflict induces different cognitive interpretations, which viewers may encounter while watching. Moreover, temporal multiplexing and crosstalk occur due to the persistent auto stereoscopy during surgery, in which the image content of the eye is still visible in the next frame when that eye is exposed to a new view. Temporal multiplexing can also induce flicker seen in the visual periphery. This disrupts the vision in large field-of-view immersive auto stereoscopy. This happens as conditions may stimulate the magnocellular dominated dorsal-cortical pathway, which draws connections from the peripheral retina, and above all have a transient response and high temporal acuity, perceived as flicker.

The complex time-related neuro-cognitive output, linked to visual perception as the first input, is a process of response that crosses the limbic area, the hypothalamus–adrenal axis up to the prefrontal cortex and the pre-motor association area. The performance is therefore conditioned by these events, to what happens in the learning curves and memory clusters of experience for skill [73]. The neuro-cognitive basis can define an involuntary human error. Training, methods or technologies for correcting individual perceptual limits, represents risk management for performance to which an individual is appointed to implement [74].

Visual perception and cognitive performances are critical points for the surgeon, which has a predetermined but ever-changing set of tasks that must be performed. This performance is strongly affected by the amount and quality of the visual input, as well as by the resultant visual perception and cognitive performance.

War-fighter military studies about hyperstereopsis and cognitive errors onto the use of binocular magnification introduce the possibility of having mismatches between the imagery presented to the two eyes [75]. There are numerous reasons for this, some of which are induced by alignment errors as the racial conformation of the skull and inter-pupillary distance, body position and posture between optical image, and the host modulating tolerance limits as vertical convergence and/or divergence misalignments. Other factors include rotational, type of magnification and luminance and colors at the scene [76]. Thus, a variable of stereo imperfections is induced by many factors such as the tuning of displays for application crosstalk optical errors (i.e., spatial distortions), imperfect filters (i.e., photometric asymmetries including luminance, color, and contrast), and stereoscopic disparities [77, 78].

The learning curve in video-assisted surgery is facilitated by systems that provide accurate human perception for tridimensional visual information by using intuitive imaging. Notably, the so-called *true tridimensional* [79] is focused to render left-eye and right-eye images in an apparent image parallax. Theoretically, the difference in the position of the surgical scene depicted in the rendered left-eye and the right-eye images should approximate the difference that would occur if the scene were viewed along two different lines of sight, associated with the positions of the left and right eyes. So, depth perception reaches the stereoscopic depth. Realistic stereopsis is triggered by this apparent image parallax, improving depth acuity (the ability to resolve depth in detail) in an individual.

Furthermore, the sequence of left-eye and right-eye images may include the perception by the individual of taking hold, seizing, grasping or, more generally, interacting with the scene.

This capability may be facilitated by a digital simulator using inputs (algorithms) to modify the graphical system interaction between the individual and the tuned displayed visual information. In addition, the depth acuity offered by the algorithm-graphical system and the simulator may be enhanced through the use of monoscopic depth cues, such as: relative sizes/positions (or geometric perspective), lighting, shading, occlusion, textural gradients, and/or depth cueing.

Thus, algorithm-simulator and graphics for ad hoc applications may allow the individual to combine cognition to a deliberative conscious mental process, by which one achieves knowledge and intuition as an unconscious mental process without inference or deliberative thought. This synergistic combination may further increase the individual's knowledge to skill and allow them to use the simulator or new generation of graphical system to perform tasks more accurately and more efficiently. This capability may allow a physician to synthesize the emotional function of the right brain with the analytical functions of the left brain, to interpret the virtual images as a more accurate and acceptable approximation of reality. Alternatively, surgeons can use this capability in several situations: planning surgeries, performing virtual surgeries (for example, to rehearse a surgery), sizing implantable devices, using live or real-time image data to work on a virtual or a real patient during surgery. Collectively, these features may improve patient outcomes and may reduce the cost of providing medical care by simply optimizing the learning curve and risk management, as an addition to the previously described training tasks.

9.12 Summary

"Seeing one, then Doing one" is the dogma that most adult surgeon has believed in for the very first part of their career. Thinking of surgical training is often connected to the concepts of advanced skills training, meaning the acquisition of a full procedure, but in the last decade, we have learned that this is just the final part of a long journey. Training a full procedure for the first time on a patient is not acceptable anymore and literature is full of studies focused on how to make the process straightforward, in other words, optimizing the learning curve. Several authors have shown that the approach to a full procedure needs a progressive path, better if it is proficiency-based, and provided with comprehensive metrics (Table 9.1). The process has also got to be feasible and easily adaptable, and therefore the introduction of intermediate steps to break-down parts of the procedure to minimize costs and allow more access to quality education. Despite the development of metrics and methodologies for advanced training, it is undoubtedly complex and requires several factors to be involved, development of protocols, being tested and slowly adopted. While standardization is increasing at all levels, the last frontier of education may be the adaptation of standards to individual abilities, which could enable competence in even higher goals. We are in the middle of an unprecedented revolution in surgical education that will have a direct impact on the competencies and the surgical treatments of tomorrow. The exponential growth of technology has increasingly pushed forward the democratization of these novel methodologies and this is probably just the beginning of a new era for patient safety.

Table 9.1 Validation studies for advanced urological procedure simulation

Simulation model	Pyeloplasty model	Pyeloplasty model	VUA	VUA	VUA	VUA	MVI	Partial nephrectomy	Partial nephrectomy	Partial nephrectomy	Ureteral anastomosis	Simbionix RARP
Study reference	[24]	[30]	[34]	[39]	[40]	[41]	[42]	[43]	[44]	[47]	[48]	[68]
Face validity	Y (low)	Y	–	–	–	Y	–	–	–	–	–	Y
Content validity	Y	–	–	–	–	Y	–	–	–	–	–	Y
Construct validity	Y	–	–	–	–	Y	–	–	–	–	–	Y
Predictive validity	Y	–	–	–	–	–	–	–	–	–	–	–
Level of evidence	III	IV	IV	II	IV	III	IV	V	III	IV	IV	II
Level of recommendation	B	C	C	B	C	B	C	D	C	C	C	B

UVA vesicourethral anastomosis; *MVI* major vessel injury

Key Points
- Introduction to the field of modern surgical simulation.
- State of the art in surgical training protocol-development methodology.
- Intermediate training definition and models available.
- Advanced training definition and models available.
- Perception as a novel variable to be considered in surgical training.

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Chapter 10
Cystoscopy and Ureteroscopy Simulation

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10.1 Introduction

Intensive training of surgical competencies is paramount for a surgical medical specialty, such as urology. Supervised clinical instruction and guidance in the operating room or office setting are traditionally expected for any skill development. However, the traditional approach of the education model is limited by medicolegal and ethical concerns, higher cost containment, and a longer period of training [1, 2]. Additional factors include a change in patient's behavior, knowledge, and attitude. Thus, the development and improvement of surgical skills on patients seems to be unacceptable [3]. The issue is further magnified with the implementation of regulations limiting the working hours of trainees. As such, the training hours of residents were restricted to 8000 hours and 3–5 years [4]. On the other hand, the continuous development of endourological procedures and the introduction of novel technologies demand an environment for the rapid acquisition of skills in a standardized manner.

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Historically, Halsted's paradigm, with the motto "see one, do one, teach one" requiring an extensive period of hands-on training with patients, was considered best for the development of the required surgical competencies [5]. The criticism of the apprenticeship model included its unstructured methods and variability of educational process and outcomes [6]. The model was autocratic and strictly pyramidal, allowing only a limited number of residents to reach the level of staff surgeon [5]. In the last two decades, Miller's pyramid with the core structure of "Knows, Knows how, Shows how, Does" has been widely adopted for the assessment of clinical competencies during the education of many health professions [7]. The principle of this model is the acquisition of technical skills prior to the performance of the procedure in real-life situations.

10.2 Benefits of Simulation in Urethro-Cystoscopy (UCS) and Ureterorenoscopy (URS)

Endoscopic and minimally invasive procedures are a mandatory attribute of modern urological practice. These procedures, used for both diagnostic and therapeutic purposes, require adequate training and the development of technical and non-technical skills. It has been shown that extensive clinical experience was associated with a reduced rate of complications and better outcomes [8]. However, changes in haptic feedback, restricted visual field, and technical difficulties with the usage of different instruments, particularly in ureteroscopy (URS), make these procedures very challenging [9]. In this context, simulation of the surgical environment represents a good alternative for training novice specialists.

As defined, simulation is a device or exercise that facilitates the replication of real-life scenarios under test conditions [10]. Simulation is particularly useful in the training of endoscopic surgeries, which incorporates video technology with fixed instrument-access sites and a limited number of approaches and techniques [8]. The aforementioned simulation training allows the generation and repetition of standardized surgical steps. As such, several benefits of simulation can be encountered. Similar to flight simulators, the artificially created environment can promote the development and improvement of technical and surgical skills without endangering a patient's well-being [11]. Trainees can learn about the instruments, become familiar with the procedures, and have the possibility to focus on the steps in a calm and consequence-free environment. In addition, mentors with attentive instructions can guide the trainees without worrying about the patient [2].

The repetition of the simulation training can improve not only the technical skills of specialists but also result in a better tolerance of the procedure. When investigating the effect of simulation on mental workload, Abe et al. found a persistent decrease in the latter over the simulation sessions [9]. Thus, the side effects of a high mental workload, increased fatigue, and errors could be minimized only after several sessions of simulation training.

10.3 Methods of Surgical Simulations

Surgical simulation can be achieved through a wide variety of methods, including dry and wet laboratories. With technological advancements in computer-based virtual reality (VR) surgical models have emerged. All of the above-mentioned methods are used for the training of endoscopic skills [12].

10.3.1 Dry Laboratories

The utilization of bench models is one of the methods for simulation both in urethrocystoscopy (UCS) and in URS. Targeted and specifically designed models can assure the development of particular skills, introduction to the instruments, and their safe use. These models allow the development of all four phases; cognitive, integrative, autonomous, and basic psychomotor skills [13]. The stimulation as in cognitive phase you stimulate the mental model actions to analyze the order and the steps required to complete the task. During the integrative phase, respective motor behavior is provoked based on the accumulated knowledge. With the repetition of the training autonomous phase is reached, minimizing, or even eliminating the cognitive component from the task [13].

10.3.2 Wet Laboratories

These training methods use human cadavers or live animals for training purposes. In addition to the development of basic psychomotor skills, the introduction of anatomical particularities, realistic instrument positioning, and haptic feedback can be achieved. Nonetheless, several constraints are related to the wide use of wet "labs." Specifically, these methods are associated with significant ethical concerns and costs. Both methods need dedicated organization, which cannot be achieved all the time. Furthermore, working time restrictions and the possible injury of anatomical structures during training limit their availability to all students and specialists. For training on live animals, surgical and anesthesiology kits together with the respective teams are also required. Moreover, the absence of vital signs such as bleeding and respiratory movements is another limiting factor for cadaveric models [12, 14].

10.3.3 Virtual Reality

During the last two decades, the rapid improvement of computer technologies allowed the development of virtual reality (VR) simulators for many of the medical and surgical fields. These models are particularly suited for video-assisted surgeries such as endoscopy and laparoscopy. The computer perceives human movements, analyzes them, and depicts the outcome on the screen. Thus, trainees can navigate and move the instruments and receive feedback in real-time [12].

The VR models offer several advantages. First, not only technical skills can be developed but also specific surgical procedures can be practiced. Second, training can be performed over and over in a safe environment without any working time restrictions. Third, having the possibility of recording the mistakes and integrating interactive feedback, the skills can be acquired without the presence of a mentor. Finally, there is no need for a specific organization, utilization of surgical or other materials, or involvement of other team members. Training is readily available at any time [12]. Apart from the purchase cost, a potential limitation of this method is that learners practice skills for the simulators, which are not always equally translated to clinical scenarios.

10.4 Validation of a Training System

Before a training model can be implemented and offered as an alternative method for improving surgical skills, its effectiveness and reliability should be proven. Several validation criteria could be used to objectively describe a model. These criteria include face (the ability to resemble the real procedure), content (the ability to simulate the development of skills required for a procedure), construct (the ability to differentiate novices from experts), discriminate (the ability to discriminate the skills of individuals with similar training background), concurrent (the ability to correlate with the existing gold standard alternative), and predictive validity (the ability to predict the real-life performance) [15]. Apparently, the construct and predictive validity criteria represent the most important criteria for consideration.

10.5 Skill Assessment Tools

A variety of models are available, and an important question to answer is which training model is best available for each surgical procedure [16–19]. The marketing attraction provided by companies with VR training models sometimes overshadows the reality of measurable benefits. In order to have a reliable objective comparison of gained technical and non-technical skills, validated assessment tools were developed [17, 18].

The endoscopic stone treatment step 1 (EST s1) curriculum allows training and examination of standardized tasks and includes 4 tasks: flexible cystoscopy, rigid cystoscopy, semi-rigid ureteroscopy, and flexible ureteroscopy [16] (Fig. 10.1). In an assessment of 124 participants, the breakpoint analysis showed a significant change in performance curve at 36, 41, 67, and 206 s, respectively, corresponding to 30, 60, 25, and 120 clinical cases for each of the 4 above-mentioned tasks.

Score Form EST Step 1

EUROPEAN SCHOOL OF UROLOGY

Name of Examinee	Name of Examiner

Trainees get one-minute warm up before Task 1

Task 1 – Flexible cystoscopy **Time start:** scope enters the bladder (bladder neck) **Time stop:** when guidewire touches the third mark Guidewire pre-loaded in the cystoscope	**Trial 1**	**Trial 2** (only if trial 1 failed)
Time to complete task: To pass: **0.36** or less	(Min:sec)	(Min:sec)
Quality Criteria Scope correctly used and positioned	OK / Not OK	OK / Not OK
Markers (x 3) touched with guidewire as requested (within 1mm) (Critical) (by moving the guidewires in and out)	OK / Not OK	OK / Not OK
Tutors' navigations requests carried out correctly	OK / Not OK	OK / Not OK
Task 2 – Rigid cystoscopy **Time start:** scope enters the bladder (bladder neck) **Time stop:** scope exits the bladder Guidewire pre-loaded in the cystoscope	**Trial 1**	**Trial 2** (only if trial 1 failed)
Time to complete task: To pass: **0.41** or less	(Min:sec)	(Min:sec)
Quality Criteria Cystoscope correctly assembled in 1 minute **start: trainee touches the cystoscope** **stop: trainee correctly assembles the cystoscope**	OK / Not OK	OK / Not OK
Tutors' navigations requests carried out correctly	OK / Not OK	OK / Not OK
Markers (x 2) touched with guidewire as requested (within 1mm) (Critical) (by moving the guidewires in and out)	OK / Not OK	OK / Not OK
Ureteral orifice correctly cannulated with the guidewire (4 cm) (Critical)	OK / Not OK	OK / Not OK

Fig. 10.1 Assessment form for Endoscopic Stone Treatment (EST) Step 1

Task 3 – Semi-rigid ureteroscopy **Time start:** scope enters the bladder **Time stop:** scope exits the bladder with both guidewires in place Working guidewire pre-loaded in the ureteroscope **Access sheath placement not in time-count**	**Trial 1**	**Trial 2** (only if trial 1 failed)
Time to complete task: To pass: **1.07** or less	(Min:sec)	(Min:sec)
Quality Criteria Ureteral lumen in the center of the screen majority of time (during ureteroscopy)	OK / Not OK	OK / Not OK
Working (second) guidewire successfully placed	OK / Not OK	OK / Not OK
Access sheath is wet and correctly assembled	OK / Not OK	OK / Not OK
Access sheath successfully inserted (Critical)	OK / Not OK	OK / Not OK
Task 4 – Flexible ureteroscopy **Time start:** scope enters the access heath **Time stop:** scope comes out of the box along with the access sheath under direct vision	**Trial 1**	**Trial 2** (only if trial 1 failed)
Time to complete task: To pass: **3.26** or less	(Min:sec)	(Min:sec)
Quality Criteria Scope orientation maintained through the procedure	OK / Not OK	OK / Not OK
Calices from 1 to 6 visualized correctly with the tip touching the number (Critical)	OK / Not OK	OK / Not OK
Calices from 7 to 10 visualized correctly with the tip touching the number (Critical)	OK / Not OK	OK / Not OK
Scope and access sheath removed safely and under direct vision (Critical)	OK / Not OK	OK / Not OK

Fig. 10.1 (continued)

Global performance assessment

Depth perception (scale 1-5, pass: minimum 3)				
1. Constantly overshooting target, hits backstops, wide swings, slow to correct	**2.**	**3.** Some overshooting or missing plane, but corrects quickly	**4.**	**5.** Accurately directs instruments in correct plane to target
Bimanual dexterity (scale1-5, pass: minimum 3)				
1. Use of one hand, ignoring non-dominant hand, poor coordination between hands	**2.**	**3.** Use of both hands, but does not optimize interaction between hands to facilitate conduct of exercise	**4.**	**5.** Expertly uses both hands in a complementary manner to provide optimal working exposure
Efficiency (scale1-5, pass: minimum 3)				
1. Uncertain, much wasted effort, many tentative motions, constantly changing focus of exercise or persisting a task without progress	**2.**	**3.** Slow but planned and reasonably organized	**4.**	**5.** Confident, efficient, and safe conduct of operation maintaining focus on component of procedure until better done by another approach

Personal training advice from the tutor

Fig. 10.1 (continued)

The Objective Structured Assessment of Technical Skills (OSATS) is an intensively validated instrument used for the assessment of technical skills. It includes 3 scoring systems: a detailed task-specific checklist, a global rating scale with a total of 7 items, and a pass/fail scoring system [17]. Each item of the global scoring system is assessed with a 5-point Likert scale, with the maximum score of the system reaching 35 points.

More recently, the Global Assessment of Urological Endoscopic Skills (GAUES) has been designed to assess endourological skills during cystoscopy, ureteroscopy, and transurethral resection [19]. The tool includes 3 categories, each consisting of 3 task-specific items scored according to a 5-point Likert scale and 2 global-rating skill items with a maximum 4-point Likert scale. The categories are scope handling, examination quality, and therapeutic skills. In total, 130 residents were included in the assessment study. Significant differences between novice and intermediate level residents were detected in almost all domains. The tool showed face, content, and construct validity with excellent reliability and was suggested for the assessment of endourological training skills [19].

For the assessment of non-technical skills, the Non-Technical Skills for Surgeons (NOTSS) rating scale was proposed [18]. This behavior rating scale was designed to assess 4 critical categories (each having 3 elements) of non-technical skills, such as situation awareness, decision-making, leadership, communication and teamwork. These skills are necessary for the successful completion of surgery. Specific elements of each category were the following (see Chap. 17 for more discussion on this topic):

1. Gathering information, understanding information, projecting and anticipating future states (situation awareness component).
2. Considering options, selecting and communicating options, implementing and reviewing decisions (decision-making component).
3. Setting and maintaining standards, supporting others, coping with pressure (leadership component).
4. Exchanging information, the establishment of a shared understanding, coordinating a team (communication and teamwork component).

Each category can score up to 4 points, resulting in a maximum score of 16 for the whole scale [18, 20].

10.6 Training and Simulation in UCS and URS

10.6.1 Commercially Available Simulator Models

The diagnostic rigid and flexible UCS is the minimum requirement of any urologic department or office. Being a relatively easy procedure, appropriate training can still improve and speed up the development of basic skills. A study assessing the training needs revealed that cystoscopy, ureteral stent placement, and transurethral resection of the bladder tumor (TURBT) along with a transrectal ultrasound-guided biopsy and suprapubic catheter placement were the highest prioritized procedures for simulation-based training [21]. Different training low- and high-fidelity models have been evaluated so far. Although fidelity is not well-defined, the "realism" of the model mimicking normal human anatomy was suggested for achieving proper definition [22].

Commercially available inanimate bench models such as the Uro-Scopic Trainer (Limbs and Things, Bristol, UK) and the Scope Trainer (Mediskills Ltd., Edinburgh, UK) gained popularity due to the realistic recreation of the genitourinary tract, features like distensible bladder and the presence of ureteral orifices, which allowed the performance of cystoscopy and ureteroscopy training [2].

Further improvement of the UCS training is associated with the introduction of VR models. The URO Mentor™ (3D systems, Cleveland, OH, USA) is the first and most widely used VR model in UCS (Figs. 10.2 and 10.3). The device incorporates a mannequin connected to a computer. Similarly, the PERC Mentor™ (3D systems, Cleveland, OH, USA) provides training in percutaneous renal access under

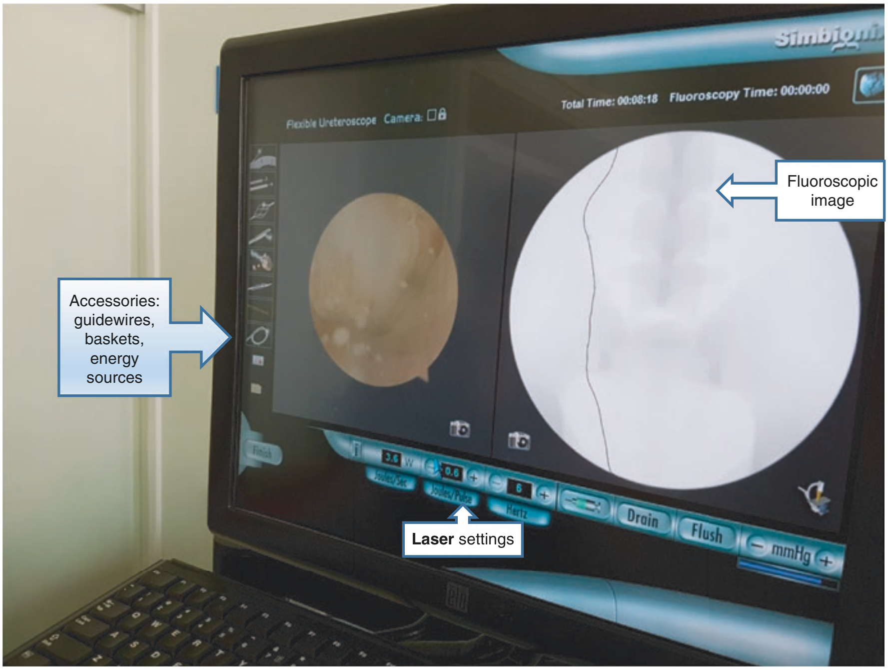

Fig. 10.2 URO Mentor™ monitor showing the accessories, fluoroscopic image, and laser settings of the lithotripsy

fluoroscopic guidance. In addition to diagnostic UCS, URS, and PCNL, they offer training of different surgical procedures having the ability to depict complications such as bleeding and ureteric perforation. The availability of comprehensive feedback makes this tool very effective for training [12]. The system features a working channel for tools such as virtual guidewires, baskets, stents, and energy devices. It is completed with simulated X-rays with an option to alter the laser to pneumatic device settings. The face, content, construct, concurrent, and predictive validity of the model for cystoscopic and ureteroscopic procedures have been investigated in many studies [1, 23–26], some of them carrying a high level of evidence [27].

Shah et al. were one of the first to evaluate the URO Mentor™ for training flexible UCS [24]. The study included 14 urology nurse practitioners without any experience in cystoscopy. Significantly shorter task time was reported after completing the single session training course. Significant linear improvement in the performance of cystoscopic basic skills was observed in another study by Gettman et al. [1]. A steady state of performance was reached after 6 sessions with all novices, regardless of gender. A successful outcome was also demonstrated for therapeutic cystoscopic procedures, such as bladder biopsy and coagulation. Evaluating 89 individuals, an overall appraisal score of 7.3 out of 10 points was reported [23].

The URO-Trainer (Karl Storz GmbH, Tuttlingen, Germany) is another VR simulator introduced to the market [28]. It comes with a simbox (for haptic force

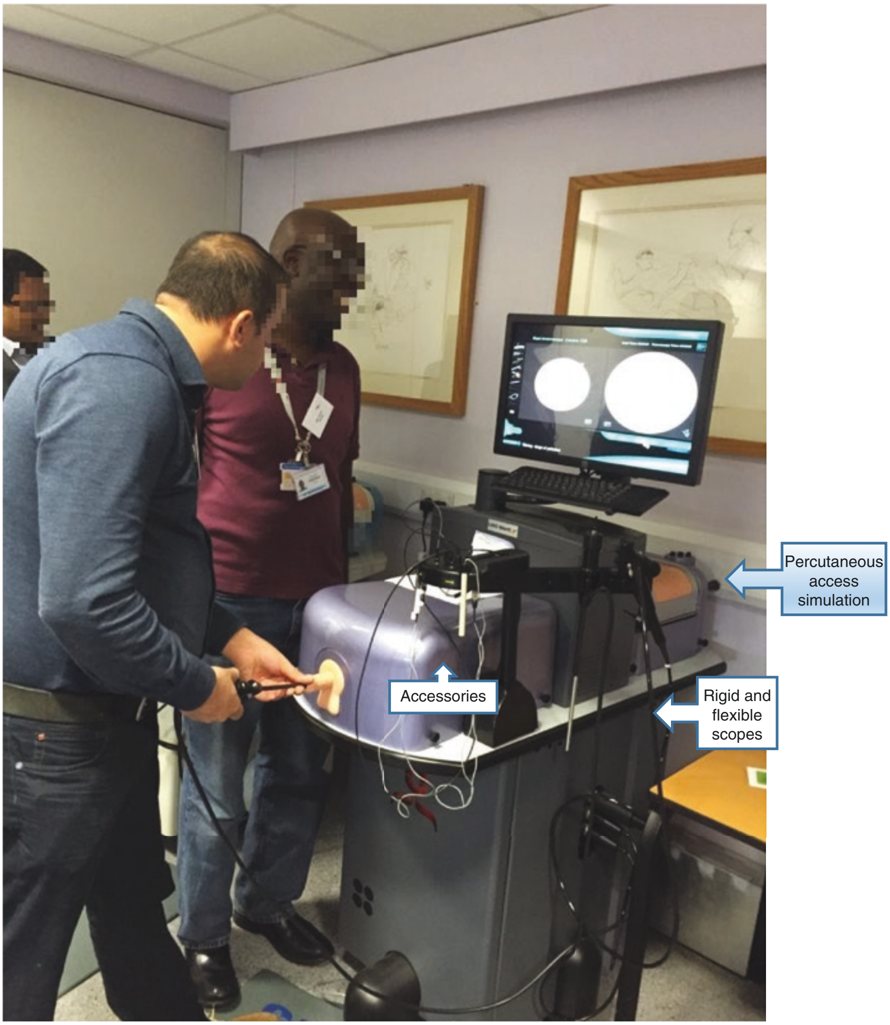

Fig. 10.3 URO Mentor™ simulator showing an overview of the scopes and the monitor

feedback), a resectoscope (passive and active), and software (for TURP and TURBT). Having similar characteristics with the URO Mentor™, this simulator is less studied in the literature. Its effectiveness has been evaluated for the development of technical skills for cystoscopy TURBT and transurethral resection of the prostate (TURP) [28, 29]. The benefits of this system were rated with a high score of 8.5 out of 10 for the TURBT [28]. Similarly, the educational value was high for TURP, especially for novices in the procedure [29].

Ureteroscopy is probably one of the most challenging endoscopic procedures not only for novices but sometimes also for experts. The procedure is associated with significant mental and physical strain. It requires the use of several long instruments, various surgical materials, such as guidewires, baskets, and lasers. The equipment is expensive and fragile; therefore, planning and meticulous movements are extremely important. Apparently, the operative room is suboptimal for the development of technical skills, especially for this procedure. Therefore, there is a large piece of research assessing different models for the acquisition of ureteroscopic skills. In 2017, the number of publications on simulation in URS was 48 with a significantly rising interest in the topic in recent years [30].

As for simulation in UCS, ureteroscopy simulation can be achieved using all available simulation models. The aforementioned commercially available three training models, 2 high-fidelity bench models (the Uro-Scopic Trainer (Limbs and Things, Bristol, UK) and the Scope Trainer (Mediskills Ltd., Edinburgh, UK)) [2], and 1 VR simulator (the URO Mentor™ 3D systems., Cleveland, OH, USA) [12], have all been actively studied for URS training.

The educational value of the 2 high-fidelity bench models has been shown in the literature [31, 32]. Matsumoto et al. evaluated the construct validity and educational impact of the Uro-Scopic Trainer [32]. Among 17 trained residents, a higher score was reported in the senior group compared to junior residents. Two other studies compared the above training system to the URO Mentor™. In both of the studies, training resulted in an improvement in scores regardless of the training system used [8, 33].

The Scope Trainer was tested in 2 studies, both of them conducted by Brehmer et al. [31, 34]. According to them, senior residents' performance was significantly better than that of junior residents. The first study included 14 urologists. In addition to showing the construct validity of the bench model, the residents reported that the training was similar to the real surgery [34]. The second study with 26 urology residents found improved overall scores after the training, emphasizing the educational impact of the Scope Trainer in the acquisition of the technical skills for the URS [31].

The URO Mentor™ simulator is probably the most investigated in the field of endourology. In 2002, 3 studies already assessed its effectiveness for URS [35–37]. Michel et al. were the first to describe the simulator and its related advantages [37]. Thereafter, Wilhelm et al. and Watterson et al. investigated the system in randomized controlled settings [35, 36]. In both studies, post-test scores were significantly better in individuals with VR training. The trained group showed significant improvement in the ability to perform the task, overall performance, and total evaluator score [35]. Better performance of novice specialists and a reduction in procedural time were documented in further studies [38, 39]. Jacomides et al. found that a total of 5 hours of training during multiple sessions improved the skills of students similar to that of residents at the end of the first year of urology training [38].

Similarly, better outcomes were reported by other authors [20, 40–42]. A curriculum-based training on the URO Mentor™ resulted in significant improvement of all technical and non-technical parameters of residents [20]. Khan et al. developed and implemented a centralized simulation training module [43]. As expected, senior participants performed better than junior colleagues.

The concurrent validity of the simulator was tested by Matsumoto et al. comparing it to a validated high-fidelity URS bench model [44]. The overall performance and procedure time were superior in the VR group. No difference in skills gained between the VR simulator and the high-fidelity bench model was also reported in a study by Chou et al. [8].

Currently, an international multi-institutional randomized clinical trial, Simulation in Urological Training and Education (SIMULATE), is in the phase of recruitment [45]. The participants will be randomized to simulation-based training and non-simulation-based training. The URO Mentor™, Uro-Scopic Trainer, and Scope Trainer models will be used for simulation. The primary outcome of this study will be the number of procedures required to reach proficiency. Hopefully, the study will bring transparency to the field and demonstrate the real impact of training simulators on the development of today's residency program curriculums (Tables 10.1 and 10.2).

10.6.2 Low-Cost Simulation Methods in UCS and URS

In an attempt to review low-fidelity training models for UCS with material costs of less than 150$ only 3 studies met the criteria [50]. The bench models were made from a glass globe-shaped food container [51], balloon [52], and vegetable components (pumpkins and green peppers) [53]. With average educational values, all the models were easy to construct. Only one paper evaluated the construct validity [52]. Similar bench models have also been reported to positively affect the training of novice specialists [54–56]. These low-cost models can be utilized as a first step for cystoscopy skill development.

For the training of URS skills, Matsumoto et al. described an inexpensive low-fidelity bench model [46]. The model was constructed from a Penrose drain, an inverted cup, a molded plastic case, and 2 embedded straws to resemble the urethra, bladder, and ureters. This model was significantly better than a didactic session. When comparing this low-fidelity model with available high-fidelity alternatives, no significant differences were observed. Thus, spending only 20$ the authors were able to show comparable results [46].

A fully reconstructed anatomically correct transparent and non-transparent training system has been recently designed to allow the training of cystoscopic and ureteroscopic procedures [54]. The model was fabricated using silicone rubber, transparent poly-methyl-methacrylate acrylic (P-M-MA), and acrylonitrile butadiene styrene resin. The performance of 36 first-year medical students was evaluated after students were randomly assigned to receive verbal instruction or training either with transparent or non-transparent models. The group with transparent simulators was associated with better outcomes compared to the non-transparent and verbal instructions only group [54].

Another model mimicking the upper collecting system was proposed by Brazilian colleagues [57]. After injecting yellow polyester resin into the ureters of cadavers,

Table 10.1 Studies on most used simulation training models of urethro-cystoscopy (UCS) and ureterorenoscopy (URS)

Study	Procedure	Study population N	Study population Demographics	Face validity	Content validity	Construct validity	Predictive validity	Concurrent validity	LoE[27]
Uro-Scopic trainer (Limbs and Things, Bristol, UK) – Bench trainer									
Matsumoto et al., 2001 [32]	URS	17	Residents			√			2c
Matsumoto et al., 2002 [46]	URS	40	Medical students			√			1b
Matsumoto et al., 2006 [44]	UCS	16	Residents	√		√		√	2c
Chou et al., 2006 [8]	URS	16	Medical students					√	2a
Mishra et al., 2011 [33]	URS	21	Urologists	√		√			2b
Brunckhorst et al., 2015 [20]	URS	32	Medical students	√		√			2a
Scope trainer (Mediskills Ltd, Edinburgh, UK)- bench trainer									
Brehmer et al., 2002 [34]	URS	14	5 trainees, 9 consultants	√	√	√			2b
Brehmer et al., 2005 [31]	URS	26	Residents			√			2c
URO Mentor (3D systems, Cleveland, OH, USA) – Virtual reality simulator									
Michel et al., 2002 [37]	URS	N/A	Urologists	√	√				4
Wilhelm et al., 2002 [35]	UCS, URS	21	Medical students			√			2a
Watterson et al., 2002 [36]	URS	20	Novices	√		√			2a
Shah et al., 2002 [24]	URS	14	Urology nurses			√			2c
Ogan et al., 2004 [39]	URS	32	16 students, 16 residents			√	√		2b
Jacomides et al., 2004 [38]	URS	32	16 students, 16 residents			√			2b
Knoll et al., 2005 [40]	URS	20	Urologists			√	√		2c
Matsumoto et al., 2006 [44]	URS	16	Residents	√		√		√	2b

(continued)

Table 10.1 (continued)

Study	Procedure	Study population N	Demographics	Face validity	Content validity	Construct validity	Predictive validity	Concurrent validity	LoE[27]
Chou et al., 2006 [8]	URS	16	Medical students					√	2a
Gettman et al., 2008 [1]	UCS	57	30 novices, 27 experts	√		√			2b
Schout et al., 2009 [42]	UCS	100	Interns				√		1b
Dolmans et al., 2009 [23]	UCS, URS	89	33 referents, 56 experts	√	√				4
Schout et al., 2009 [41]	UCS	80	50 novices, 30 experts			√			2b
Gettman et al., 2009 [47]	UCS	10	Novices	√		√			2c
Mishra et al., 2011 [33]	URS	21	Urologists	√		√			2b
Persoon et al., 2011 [25]	UCS	86	Medical students			√			1b
Khan et al., 2012 [43]	UCS, URS	33	Trainees	√	√	√			2b
Zhang et al., 2013 [26]	UCS	18	Urologists			√			2c
Aloosh et al., 2016 [48]	URS	8	Urologist				√		2c
Bube et al., 2020 [49]	UCS	32	Trainees				√		2a
Aydin et al., 2020 (recruiting phase) [45]	URS	47	24 trainees, 23 urolithiasis specialists						1b

UCS urethro-cystoscopy, *URS* ureterorenoscopy, *LoE* Level of evidence according to Carter et al. [27]

Table 10.2 Specific models on most used simulation training models of urethro-cystoscopy (UCS) and ureterorenoscopy (URS)

Name of the model	Description	Use	Strengths	Limitations
Uro-Scopic trainer *(Limbs and Things, Bristol, UK)*	Inanimate high-fidelity bench model comprising mannequin of the male genitourinary tract	UCS, URS	– Training of basic skills of rigid and flexible UCS and URS – Therapeutic procedures such as lithotripsy and stone extraction – Portability and compatibility – Use of real surgical instruments mimicking a real surgery environment – Relatively cheap compared to VR models	– Need for additional working instruments – Need for instructor-guidance
Scope trainer *(Mediskills Ltd, Edinburgh, UK)*	Inanimate high-fidelity bench model following the course of male urinary system anatomy	UCS, URS	– Training of basic skills of rigid and flexible UCS and URS – Therapeutic procedures such as lithotripsy and stone extraction – Portability and compatibility – Use of real surgical instruments mimicking a real surgery environment – Relatively cheap compared to VR models – Possibility to couple the model to percutaneous-access trainer and establish a complete urinary system	– Need for additional working instruments – Need for instructor-guidance
URO Mentor™, *(3D Systems, Littleton, USA)*	Virtual reality model incorporating a mannequin connected to a computer	UCS, URS, PCNL	– Training of basic skills of rigid and flexible UCS and URS – Simulation of fluoroscopy and C-arm control – Training of different surgical procedures – Availability of comprehensive feedback – Virtual features including possession of different wires and energy devices with multiple options – Face, content, construct, concurrent, and predictive validity	– Higher purchase costs – Training in completely artificial environment

UCS urethrocystoscopy, *URS* ureterorenoscopy, *PCNL* percutaneous nephrolithotomy, *VR* virtual reality the latter were immersed in hydrochloric acid till the total erosion of the tissue surrounding the resin. The authors then prepared two-part silicone molds on the resin using endocasts. After removing the resin, the model was ready for training use. According to the authors, the total cost required for the preparation of the model was 30$ [57]. White et al. presented their model replicating the real anatomy of the human collecting system [58]. This adult ureteroscopy trainer was created using rapid prototyping based on the imaging of the patient's computer tomography. More than 96% of participants favored this model for training purposes and 100% of them stated that the model was realistic and easy to use. In the initial study, this high-fidelity trainer proved face, content, and construct validity [58].

Several other inanimate models have also been introduced but have not gained any wide use so far [59–63]. Simulation of some skills of flexible URS (fURS) and not the whole procedure can be achieved using the Key-Box (K-Box®, Porgès-Coloplast, France) [60] and the Cook URS Trainer (Cook Medical, Bloomington, IN, USA) [62].

The Key-Box is the first bench model specifically designed to develop the spatial movements required for the proper use of a flexible ureteroscope (Fig. 10.4). It possesses several boxes with different anatomical variations. A randomized study of 16 residents identified that trained individuals had better scores compared to the non-training group. The mean time to completion of performing three main exercises was significantly shorter for the training group [60]. Like the Key-Box, the Cook URS Trainer consists of 3 different training items. In a study by Blankstein et al., 80% of participants rated the latter system as realistic. In addition, it was rated as a useful tool for training. The face, content, and construct validity were also evaluated and proven in the study [62]. One has to be careful while training as the flexible ureteroscope can be damaged if not navigated properly in the Key-Box.

A combined use of non-biological ETXY-Uro Adam (ProDelphus, Olinda, Brazil) and biological (ex vivo porcine upper urinary tract) models before training on the alive animal model was suggested to smoothen the transfer of knowledge from one bench model to another [59]. A 43.89% increase in skills from the first till the last training session was noted for the whole cohort. While face, content, and construct validity were observed, the predictive validity was not evaluated.

10.6.3 Animal and Cadaveric Models

Theoretically, these models should carry the best predictive value and be the most suitable for training clinical skills. However, their use is limited due to a number of serious constraints [12, 14].

Several authors have described the isolated ex vivo porcine urinary tract for training endoscopic skills [59, 64, 65]. According to Strohmaier et al., this training model was superior in terms of "tissue feeling" and anatomic relationships compared to non-biological systems [64]. The feasibility of the isolated porcine kidney model was further evaluated by 20 urologists for the performance of fURS. An

Fig. 10.4 Key-Box trainer for flexible ureteroscopy training

average decrease in operative time and the development of relatively stable performance were observed after the sixth session [65]. In addition, the porcine model was used for the assessment of technical skills training on other inanimate models [54].

Cadavers with different methods of fixation have been successfully used for training purposes of different procedures. Thiel-embalmed cadavers were recently described for UCS and URS with the reported benefits of mucosa color and tissue consistency preservation similar to a live patient [55, 66]. Hurr et al. presented the outcomes of an fURS training course on cadavers [67]. In total, 12 urologists with prior experience in fURS were included in the study. The training resulted in the improvement of knowledge of the procedure and was claimed as one of the best models mimicking the living human tissue [67]. Although the findings and conclusions of these training models are positive, their reproducibility and wider acceptance are very low. Moreover, cadaveric courses could be difficult to organize in most of the centers worldwide.

10.6.4 Duration of the Training

According to most of the above studies, training improves the surgical performance of individuals. But the minimum number of sessions that should be considered, remains unanswered. Based on the clinical level of the individuals, a different number of sessions may be necessary. Some of the studies reported 6–7 sessions for the competence development [1, 47, 48]. Nevertheless, improvement of technical skills for procedures such as TURP and TURBT, fURS can even be achieved with a training boot camp [68, 69] or single session training events [41]. Furthermore, such events can increase operative confidence immediately and at 3-months following the training course [68].

10.6.5 Transfer of Skills into the Operating Room

The VR simulators seem to mimic the operative steps of different endourological procedures the best way. Nonetheless, they do not provide complete realism due to the lack of real haptic and tactile sensation from the human tissues. In addition, the working instruments are similar but not the same as the ones used during the real surgery [22]. Successful transfer of the gained skills from the training into the operating room is probably the most important factor favoring the use of any training model. Aloosh et al. reported a positive predictive validity of training on the URO Mentor™ simulator [48]. In general, residents who performed better on the simulator demonstrated better results also in the operating room [48]. A similar better performance in the operating theater was observed in another study by Knoll et al. [40]. In a comparative performance of 5 residents with and without training on the URO Mentor™, residents with training performed better in the first 4 URSs in terms of operative time. Nevertheless, no difference was revealed in complication rates between the groups' [40].

Recently, the superiority of the training on the URO Mentor™ for the successful performance of UCS has been proven in a randomized controlled trial [42]. With a comparatively large sample size, 50 interns in each group, significantly better scores were reported for interns with prior training. On the contrary, Bube et al. failed to report any significant differences in transferring the skills from training into real-life surgery. None of the group participants was able to demonstrate competent and consistent performance [49]. These data show that proper training on VR simulators can significantly affect the performance of real procedures, especially during the initial cases.

10.6.6 Cognitive Training and Simulation

Performing surgery is a complex task requiring a high level of mental and physical involvement. One of the training modalities is the so-called mental practice or cognitive training. The latter is the rehearsal of the planned task before performance without any physical movement [70]. It has been shown that 30 minutes of mental practice can significantly improve the quality of the simulated surgical procedure [71].

The effect of cognitive training on surgical education has been recently evaluated on a ureteroscopy simulator in a randomized control trial [72]. All 59 participants were randomized into three groups: 20 patients in simulation training only, 20 patients in simulation plus flashcards cognitive training, and 19 patients with mental imagery cognitive training. The authors reported minimal benefits of cognitive training for the acquisition of surgical skills without any significant superiority of one cognitive training form over the other [72].

The performance might be affected by the timing of cognitive training. Sanders et al. investigated the timing of mental rehearsal on learning basic surgical skills [73]. They found that mental imagery rehearsal after initial physical practice carried better outcomes and eliminated the need for additional physical practice compared to a rehearsal before the physical practice. Given this, utilization of mental practice at the time of the simulation could save time and result in a better understanding of the surgical task.

10.6.7 Costs and Constrains

Assessment of the cost of surgical training is essential for proper decision-making. Resident training, both in the operating room and using simulation-based training, is associated with significant costs. Bridges et al. have investigated the cost of surgical training per graduating resident, including different surgeries from the University of Tennessee [74]. As such, one minute of operating room costs 4.29$ excluding supplies, indirect costs, anesthesiologist and surgeons' fees. Calculating the total hours of residents spent in the operating room, the authors reported that the cost per each 4-year training curriculum was comprised of 47,979$ [74].

Apparently, the assessment of the cost of VR simulation training is less complicated. The purchase cost of VR simulators can reach up to 85,000$, whereas approximately 3000$ is required to purchase high-fidelity bench models [8]. However, the costs for bench models are not limited only to purchase costs. To train people, these models require surgical instruments and materials, such as rigid and flexible cystoscopes and ureteroscope, guidewires, catheters, stone extraction baskets, and laser units with generators and fibers. Moreover, due to the high fragility of the instruments, repair costs should be expected as well. Adding the time (hour wage) of the instructor required to guide the training process, the total training cost for bench models can equal 80,000$, the same amount needed for VR simulators [8]. A survey of participants trained with URO Mentor™ revealed that 73% would purchase the latter if they had to work in a teaching hospital with enough financial means. While another 20% of participants answered that they would consider purchasing and only 7% refused the idea of purchasing a training model [23]. Nevertheless, the trend of utilizing VR simulators has decreased over the last few years from 17% to 5%, probably due to initial higher purchasing costs [75].

10.7 Summary

Training of surgical skills is essential for the management of surgical procedures. Simulation-based training has been proven to significantly improve individual competencies and shorten the learning curve of real-life clinical training. Many low-fidelity training models have been proposed so far. Regardless of simulator training characteristics, the use of training positively affects an individual's perception, knowledge, and readiness for real-life surgery. Better outcomes were reported in novices, although these systems were also effective for individuals with greater expertise. Simulation training affects both technical and non-technical skills. In many studies, assessment of technical skills was performed using the rigorously validated Objective Structured Assessment of Technical Skills tool. High-fidelity models were more studied and appeared to carry better outcomes. Nevertheless, the importance of low-cost, low-fidelity simulators should not be underestimated. Among commercially available simulators the URO Mentor™ VR simulator represented the most tested model. The face, content, construct, and concurrent validity was proven in many studies. The successful transfer of sessions was mostly required for the development of steady performance skills. Integration of mental practice after the initial physical training was claimed to speed the acquisition of skills. Purchasing and maintaining costs were the main factors limiting the use of simulation training models. Well-designed randomized studies are required to confirm the existing evidence and facilitate its integration into the residency training curriculum. Standardized training protocols and modular training will allow for safe and methodological acquisition of skills necessary for trainees, thereby also shortening their learning curve in this process.

Key Points

- Training in simulation allows a safe means for the development of initial surgical skills in a calm environment.
- Novices are more prone to benefit from the simulation.
- VR simulators possess greater potential for the training of various procedures.
- A combination of low- and high-fidelity simulators can facilitate a faster learning curve.
- Simulation-based training should become a mandatory component of the residency training curriculum.

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Chapter 11
Simulation for Benign Prostatic Conditions

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Abbreviations

AI	Artificial intelligence
AuR	Augmented reality
BPH	Benign Prostatic Hyperplasia
EEP	Endoscopic enucleation of the prostate
HoLEP	Holmium laser enucleation of the prostate
MR	Mixed reality
OR	Operating room
PVP	Photoselective vaporization of the prostate
TURBT	Transurethral resection of bladder tumor
TURP	Transurethral resection of the prostate
VR	Virtual reality

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11.1 Introduction

Over the past two decades, technological advances in the field of medicine have led to the emergence of new techniques and procedures, especially in surgery. The wide variety of tools available and the trend toward less invasive surgery highlights the importance of learning and training adapted to today's reality. This has brought increased awareness of the need to establish methods that replace the classical models of apprenticeship and the importance of taking into account both the improvement of technical ability and the role of non-technical skills [1, 2].

Most surgical errors happen in the operating room (OR) and according to some studies, they are more frequent during the surgeon's initial learning curve [3, 4]. This period requires increased time for performing procedures and entails higher economic costs [5]. It is understood that trainees will overcome these learning curves by treating patients, with the possible complications that this may entail. Consequently, inexperienced surgeons should follow training models that include periodic reviews that ensure the acquisition of procedural skills enabling them to adopt a new technique [6].

In urology, the variety of complex surgical methods for the treatment of kidney, bladder, and prostatic disease have involved everything from open wound surgery to minimally invasive approaches, including endoscopic, laparoscopic, and robotic surgery. The great heterogeneity and specialization in treatment types and different technologies support the concern that surgical residents may not receive the most adequate training in all of these areas [7–9]. As a result, several validated training models that allow performance optimization in the OR have been developed. Among these, surgical simulation has been established as an accepted method and has provided positive results demonstrated in different studies [10–13].

The aim of this chapter is to review the current situation of surgical training and simulation in the field of endourology, and more specifically, for the treatment of benign prostatic pathology by transurethral resection of the prostate (TURP) and endoscopic enucleation of the prostate (EEP), as well as the novelties and future perspectives of simulation techniques.

11.2 Current Status of Urology Training

Changes in surgical learning models have made the classic Halstedian prototype of "see one, do one, teach one" no longer considered an adequate method [14]. Among the different training modalities adopted for a surgeon's preparation, we find observership, e-learning, mentorship and fellowship, modular training, and simulation.

Observership consists of direct learning after observing a procedure performed by a more experienced surgeon. It has been a long-established practice that allows an initial approach to a new surgical technique and is considered in all training programs. Among its limitations, it does not allow one to improve technical ability and there is limited bibliographic evidence to support its effectiveness [15]. E-Learning is the use of the Internet and multimedia technology, that is updatable and easily accessible. E-Learning has established itself as a useful adjunct to training in the urology [16]. Mentorship includes the exchange of knowledge, practical training, and subsequent feedback from a reference with appropriate experience. Telementoring has arisen as a form of virtual training, often carried out through a real-time video that allows remote interaction between the mentor and his trainee [17–19]. Fellowships are considered formal and more specific mentorship programs with a structured learning pathway and focused on a specific area of interest that help residents and urologists gain confidence and experience in incorporating new techniques into their clinical practice [20, 21]. Modular training consists of progressive learning in steps with increasing difficulty. In this way, skills are developed gradually under supervision [22]. It is an organized method supported by scientific evidence in urology. Modular training is currently applied in many minimally invasive procedures [23]. Urology residency and fellowship programs should offer comprehensive clinical and surgical training as well as a considerable amount of daily exposure to everyday and complex cases. The biggest limitation here is probably the lack of resources, followed by the lack of standardized curricula [8, 9, 24–27].

11.2.1 Simulation-Based Training

Simulation is a tool that has appeared as another alternative among the different training possibilities in surgical techniques. It has been defined as a way of "replacing or amplifying real experiences with guided experiences that evoke or replicate substantial aspects of the real world in a fully interactive manner" [28]. Simulation is an efficient method that allows progress in the urological learning curve without putting at risk the results of the intervention in exchange for an affordable cost [29–31]. Many randomized clinical trials have demonstrated the direct benefits of surgical simulators in improving performance in the operating room [32, 33]. It also avoids the risk of iatrogenesis on the patient since the practice is carried out in a controlled environment, which is an advantage in the face of the growing importance in patient safety, patient expectations, and ethical-legal problems [12, 34]. There is also evidence for simulation to improve performance when used preoperatively as a warm-up exercise [35].

McGahie et al. published a review of the evidence available so far on simulation-based medical education. They identify several fundamental principles on which this type of training is based. Among them are the need to provide automatic feedback, deliberate practice, curriculum integration, skill acquisition, maintenance, and the importance of outcome measurement and simulation fidelity [36].

Various simulation models are available, each with their own potential advantages and disadvantages. Cadaver simulation provides great anatomical fidelity and the most authentic haptic feedback, although it requires special facilities and they are not reusable, so the high associated cost should be considered. The animal simulation also involves high cost, limited use, licensing, and several ethical considerations. The most commonly used models in endourological training techniques are simulation-based on bench-top models and computer-assisted virtual reality (VR) [37, 38]. Bench-top models are usually easily accessible, portable, and often reusable. They provide tangible sensations of the real surgical environment, although anatomical and tissue similarity may be compromised. Bench-top models, as a form of physical simulator, lack an inherent means of measuring technical parameters. VR models are reusable and usually have software for statistical data analysis that allows subsequent feedback to the trainees, providing information on the improvement of the surgical technique. As for drawbacks, they have a high initial and maintenance cost [36, 37]. Full-immersion simulation with integrated technical and non-technical skills training can provide a very close to reality experience.

Simulation-based training has therefore been a solution to part of the numerous learning challenges present in the old training schemes in the surgical field. It is essential that all simulation methods undergo an initial internal assessment using a variety of measures to show their advantages and validation according to predetermined validation criteria so that they can be incorporated into training programs in a regulated manner [39]. Among these types of measurements, we include validity (face, content, construct, concurrent, and predictive validity), educational impact, and cost-effectiveness [40, 41]. However, the constant development of new simulators adapted to technological advances means that those with the greatest evidence of their usefulness are usually the oldest, as there has been more time to study them.

As the evidence supporting the use of simulation grows, the next question we must face is how simulation should be used to ensure its maximum effectiveness [32]. The use of simulators should not be punctual or used as a one-time method of training. The gradual acquisition of skills should be part of a comprehensive and proficiency-based curriculum [12, 38, 41]. For these curricula to be effective, they should focus on the needs of routine clinical practice, and in no case should they be a substitute for subsequent improvement in the real patients' [42, 43]. On the other hand, in a recent study in which final year residents were surveyed, a slight decrease in the availability of urology surgical simulators was found in Europe [44].

The progressive recognition of simulation in urology has been reflected through the development of formal simulation training programs in various countries. For instance, the European Basic Laparoscopic Urological Skills (E-BLUS) program is a validated simulation course taught in Europe. Likewise, as part of their training, the United Kingdom requires their urology residents to complete a national simulation-based Urology Bootcamp (more details in Chap. 28) [45, 46]. In robotics, similar curricula have been developed and validated, including the Fundamentals of Robotic Surgery and the Fundamental Skills of Robotic Surgery [43].

11.3 Simulation for Transurethral Resection of the Prostate

Currently, the gold standard for the minimally invasive treatment of non-malignant prostatic diseases, and more specifically for benign prostatic hyperplasia (BPH) is transurethral resection of the prostate (TURP) [47]. Therefore, training is necessary so that all urologists have an adequate command of this procedure. A series of non-biologic simulators have been designed to allow the practice of TURP, which can be bench-top models or VR simulators (Table 11.1).

Table 11.1 Bench-top and virtual reality simulators for transurethral resection of the prostate

Simulator and Provider	Face Validity	Content Validity	Construct Validity	Predictive Validity	Kirkpatrick level	Level of evidence	Level of recommendation
Bench-top models							
Bristol TURP trainer (Limbs & Things, Bristol, UK) [48]	Yes	Yes	Yes	–	2	III	B
Resection trainer LS10 (Samed GmbH, Dresden, Germany) [49]	–	–	–	–	2	IV	D
Virtual reality models							
VR TURP Simulator (University College London, London, UK) [50]	–	Yes	–	–	1	V	D
UW TURP trainer (University of Washington, Seattle, WA, USA) [51]	Yes	Yes	Yes	–	2	III	B
TURP Simulator (university hospital Linköping, Linköping, Sweden) [52]	–	Yes	Yes	–	2	III	B
Uro trainer (Karl Storz, Germany) [53]	–	–	–	–	1	III	B
TURP Mentor (3D systems -formerly Simbionix-) [54, 55]	Yes	Yes	Yes	–	2	III	B
SurgicalSIM TURP (HelSim Ltd., USA) [51, 56].	Yes	Yes	Yes	–	2	III	B
PelvicVision (Melerit Medical, Sweden) [52, 57]	Yes	Yes	Yes	–	2	III	B
VirtaMed UroS (VirtaMed, Switzerland) [54]	Yes	Yes	Yes	–	2	III	B

11.3.1 Bench-Top Simulators

Synthetic bench-top simulators are made of artificial materials such as plastic, rubber, or latex that simulate the different organs in variable pathological states. One of the best-known simulators of this type is the Bristol TURP Trainer (Limbs & Things, Bristol, UK), which allows trainees to practice the basic steps of TURP. It is composed of a plastic chamber in which an interchangeable prostate model can be placed and allows the identification of anatomical landmarks, instrumental manipulation (a resectoscope, monopolar or bipolar diathermy, and a digital camera), real-life fluid management, and the resection of the prostatic lobes [48, 58]. Brewin et al. demonstrated face, content, and construct validity in 2014 through a study with qualitative questionnaires that also compared the efficiency of resection between two groups of inexperienced and experienced urologists. Despite this, they noted limitations regarding the reality of the bleeding and the inability to demonstrate the improvement in performance in the OR [59]. Both expert surgeons and trainees considered it to be a suitable simulation tool [48]. Unfortunately, the Bristol TURP Trainer is no longer commercially available [42].

Another bench-top simulator (Fig. 11.1) that has appeared more recently is the Resection Trainer LS10 (Samed GmbH, Dresden, Germany) which has the advantages of being able to be used with all types of resection devices, having its own irrigation system and using a substrate for resection very similar to human tissue, which gives it greater realism [60]. Although the model for transurethral resection of bladder tumor (TURBT) of this simulator has shown face, content, and construct

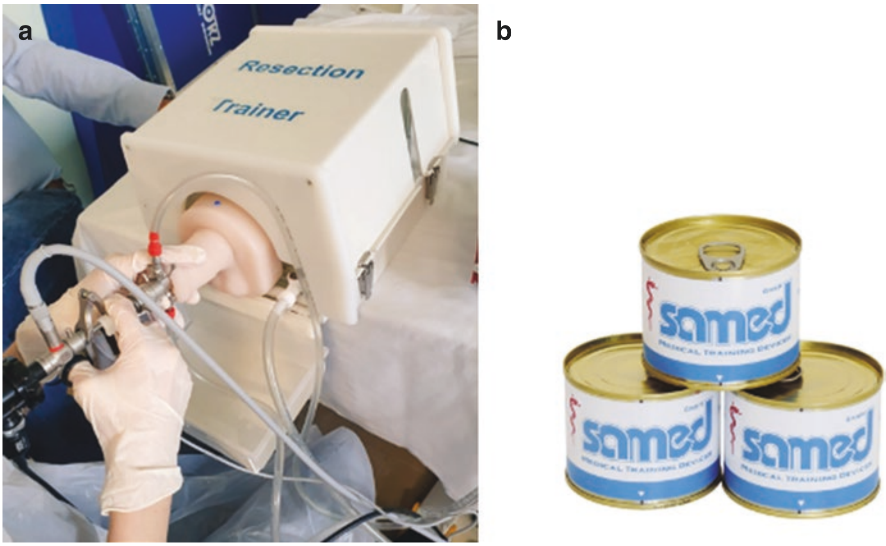

Fig. 11.1 (**a**) Samed (GmbH, Germany) prostate resection workstation and (**b**) prostate model in a tin (Reproduced with permission)

validity, the training for TURP has only been evaluated in a study on a single resident, without obtaining data to validate it [49, 61].

Choi et al. present their high-fidelity phantom 3D printed model of the prostate. The model they present is created from nontoxic materials and contains ultrasound contrast agents that improve postoperative TURP performance. The authors highlight the importance of using different materials allowing for a more realistic surgical training experience when differentiating central and peripheral prostate tissue. This model also included ultrasound contrast agents to allow for postoperative 3D reconstruction to analyze surgical performance. This diminishes the error associated with other models in which only weight change is evaluated [62]. As a limitation of this simulator, special materials must be used in order to obtain full effectiveness, which increases the cost of production. Other models have been created using animal tissue and may offer a more cost-effective approach for TURP simulation [63, 64].

Neither the predictive validity nor the educational impact has been assessed in any of the previous simulators [65]. (Table 11.2)

11.3.2 Virtual Reality Simulators

As for VR simulators, there is a greater variety, one of the first being the VR TURP Simulator (University College London, London, UK) developed by Ballaro et al. in 1999. Content validity was referred to by its creators, although the questionnaire and the results were not reported in numbers or figures. They described that the simulator's usefulness was limited by delayed images and a lack of haptic feedback [50, 65]. This is currently an outdated tool that is probably not ideal for resident training.

Following this first device, others emerged in an attempt to improve the simulation of prostate bleeding with flow-adapted images, such as the TURP Trainer developed at the University of Washington [51]. The model was described by Oppenheimer et al. in 2001 and subsequently demonstrated face, content, and construct validity in a study with 136 participants and surgeons with varying levels of experience [51, 53]. This is one of the studies on prostate simulators with the largest sample.

Another university-led initiative was the University Hospital Linköping TURP Simulator, introduced in 2005 and which provided force-feedback from the haptic device as well as improvements in the simulation of the bleeding [52]. It was the first VR simulator to enable the performance of an entire surgical procedure without interruption for changing the software module. Content and construct validity were demonstrated following a 10-item questionnaire among 9 participants, with scores on the simulator ranging from 4 to 8 after repeated use (1 = poor; 10 = very good) [57].

After this initial stage of experimentation with new VR models for surgical simulation, the industry began to develop new devices for commercialization. Karl Storz

Table 11.2 Bench-top and virtual reality simulators for photoselective vaporization and Holmium enucleation of the prostate

Simulator and Provider	Face Validity	Content Validity	Construct Validity	Predictive Validity	Kirkpatrick level	Level of evidence	Level of recommendation
Bench-top models							
HoLEP Simulator (VirtaMed, Zürich, Switzerland) [66]	Yes	Yes	–	–	2	III	B
Virtual reality models							
GreenLight SIM (American Medical Systems Inc., Minnetonka, MN, USA) [67]	Yes	Yes	Yes	–	2	III	B
MyoSim Simulator (VirtaMed, Zürich, Switzerland) [68]	–	–	Yes	–	2	III	B
UroSim HoLEP Simulator (VirtaMed, Zürich, Switzerland) [69]	Yes	Yes	Yes	–	2	III	B
RezumSim (VirtaMed, Zürich, Switzerland)	No	No	No	–	–	–	–
UroLift (VirtaMed, Zürich, Switzerland)	No	No	No	–	–	–	–

(Tuttlingen, Germany) has been developing and demonstrating the Uro Trainer, a TURBT/TURP simulator that provides force feedback. The TURP version offers modules with prostate resections ranging from 55 to 90 g, although a study concluded in 2010 revealed that it is useful for training, but probably not realistic enough [53, 70]. In a study with 22 participants, the Uro Trainer has proven its face, content, and construct validity as a simulator of basic lower urinary tract procedures and for resection of bladder tumors but not for TURP [71].

The TURP Mentor™ (3D Systems, formerly Simbionix) allows training for TURP, TURBT, and laser treatment of BPH [72]. A study by Tjiam et al. in which a total of 66 candidates were grouped according to their experience and carried out 2 TURPs on the simulator, has shown face, content, and construct validity [54]. This study also evaluates the usefulness of the simulator in the context of a urological curriculum. The manufacturer advertises it as the most advanced training simulator and provides objective performance assessment (Fig. 11.2) and optional expert-defined scores (including visualized landmarks, economy of movements, resected tissue, procedure time, safety and complications handling), while playback facilities allow further discussion and review with a trainer [55].

The SurgicalSIM TURP (HelSim Ltd., USA) simulator produces realistic movements of the scope and loop, very similar to the actual TURP [73]. It allows monitoring of learning progress through reports that analyze technical parameters of the resection such as total time, tissue resected calculated in grams, the number of cuts, amount of bleeding, the number of coagulations, and possible complications. Studies have shown face, content, and construct validity [51, 56, 73].

Another VR simulator available is the PelvicVision (Melerit AB, Linköping, Sweden) which, like the previous ones, simulates bleeding and coagulation/cutting in real-time and provides detailed technical information [74]. It is validated according to studies conducted by Kallstrom et al. in 2005 and 2010 [52, 57].

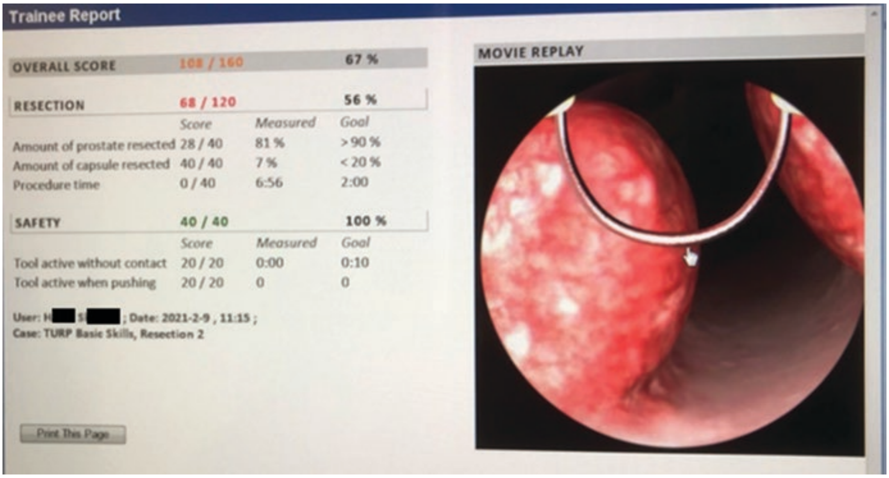

Fig. 11.2 Performance matrix on a TURP Mentor™ (Reproduced with permission)

VirtaMed (Switzerland) also offers the UroS simulator [75], enabled for the practice of TURBT, TURP, HoLEP, ThuLEP, and Diode PVP. It simulates prostatic conditions of varying degrees of difficulties and also provides a detailed report after each performance. Face and content validity have been established in two studies, while Bright et al. also demonstrated its construct validity in 18 participants [54, 55, 69].

As in the case of the bench-top models, predictive validity has not been evaluated in any of the VR models. Although it is known that the regulated use of surgical simulators implies an improvement in OR skills, there is a significant deficit of studies that evaluate this relationship and the educational impact in the field of urology [33].

11.4 Models for Laser Surgery

11.4.1 Photoselective Vaporization of the Prostate with Simulators

Shen et al. alongside the American Medical Systems Inc. (Minnetonka, MN, USA) have developed a VR simulator for GreenLight laser photoselective vaporization of the prostate (PVP) called GreenLight SIM [76, 77]. The simulator offers six different clinical cases and five exercises that evaluate: sweep agility, the distance between tissue and fiber, anatomy recognition, power settings, and coagulation. The selection of cases and exercises was done by a group of members of the American Urological Association (AUA). Both Herlemann et al. [67] and Aydin et al. [76] have validated this simulator through clinical studies. Aydan et al. performed a clinical study including 18 urologists demonstrating content, basic construct, and face validity, whereas Herlemann et al. did so through a 46-participant study [67]. In Aydin et al.'s study, evaluation of the procedural learning curve was performed by presenting 25 novice urologists with the simulator. Following simulation exercises, these novice urologists demonstrated a significant improvement in training exercises as well as a reduction in case operating time and error [76].

Another available simulator is the MyoSim developed by VirtaMed (Zurich, Switzerland) (Fig. 11.3). This VR simulator evolves as a surgical simulator for PVP. It uses the diode laser 980 nm and presents users with a variety of different HBP sizes. The simulator recreates endoscopic anatomy and morphology, allowing users to familiarize themselves with this endourologic procedure. Angulo et al., who performed a study that confirmed the construct validity of this simulator, also found that through repeated training, a decrease in procedure time and tissue abrasion was observed [68]. Furthermore, using three-dimensional reconstruction, the prostate excised volume can be evaluated, serving as a direct assessment of the effectiveness of the PVP.

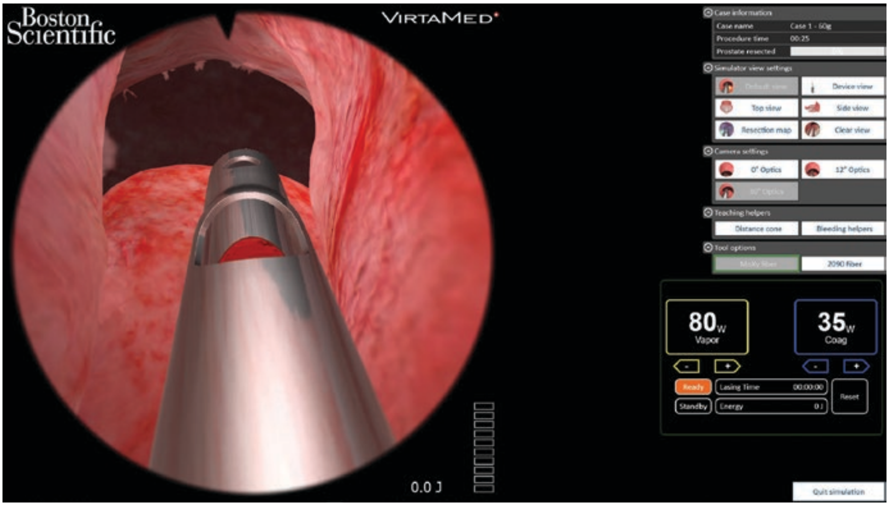

Fig. 11.3 GreenLight Simulator powered by VirtaMed (Reproduced with permission)

11.4.2 Holmium Laser Enucleation of the Prostate (HoLEP) Simulators

Holmium laser is frequently used for the treatment of BPH by EEP in what is commonly known as HoLEP. Kinoshita et al. (Kansai Medical University, Japan) developed a Prostatic Hyperplasia Model and Holmium Laser Surgery Simulator [78]. This simulator focuses on the use of a prostate model, which is then enucleated using standard surgical equipment for HoLEP surgery. As this model uses synthetic materials, the main limitation is the need to change parts of the equipment after several training sessions [78]. This simulator has been validated in face and content [66].

Other simulators have also been presented, such as the UroSim HoLEP Simulator (VirtaMed, Zurich, Switzerland) (Fig. 11.4). This is considered to be the first VR simulator for HoLEP surgery [79]. Similar to other VR simulators, the UroSim has several prostatic sizes in which to train and improve surgical techniques. Kuronen-Stewart et al. performed a 32-participant trial in which they presented content, construct, and face validity for this simulator [69]. In the UroSim HoLEP simulator, assessment of surgical skill can also be performed by evaluating: surgical duration, percentage of enucleated prostate, the efficiency of enucleation, and a safety parameter assessment [79]. UroSim has also created simulators for a wide array of surgical techniques such as TURP, ThuLEP, HoLEP, Diode PVP, and TURBT simulation [42].

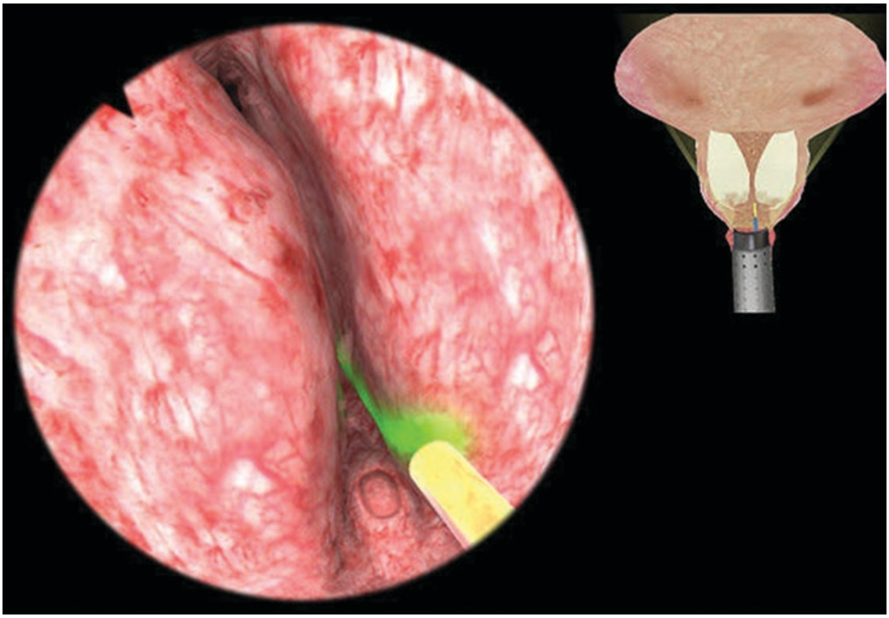

Fig. 11.4 HoLEP simulation powered by VirtaMed (Reproduced with permission)

11.4.3 Rezum™ Simulator

Rezum™ has evolved as a new treatment method for BPH offering the possibility of a less complex procedure that allows patients to preserve ejaculation. The same VirtaMed system can allow for other procedures and can currently be used for Rezum™ simulation. Face, content, and construct validity are yet to be evaluated for this simulator [42].

11.4.4 UroLift® Simulator

UroLift® System is a novel, minimally invasive technology for treating BPH. UroLift® implants lift and hold the enlarged prostate out of the way, relieving prostate obstruction symptoms by opening the urethra directly (Figs. 11.5 and 11.6). NeoTract, Inc., has created a system that allows for simulations for the treatment of BPH using UroLift®. Face, content, and construct validity are yet to be evaluated for this simulator [42].

11.4.4.1 Limitations

The main limitation regarding TURP simulators is their cost. Due to this, most training urologists will not have access to these during their residency, particularly in virtual reality simulators in which the software used to drive the application is

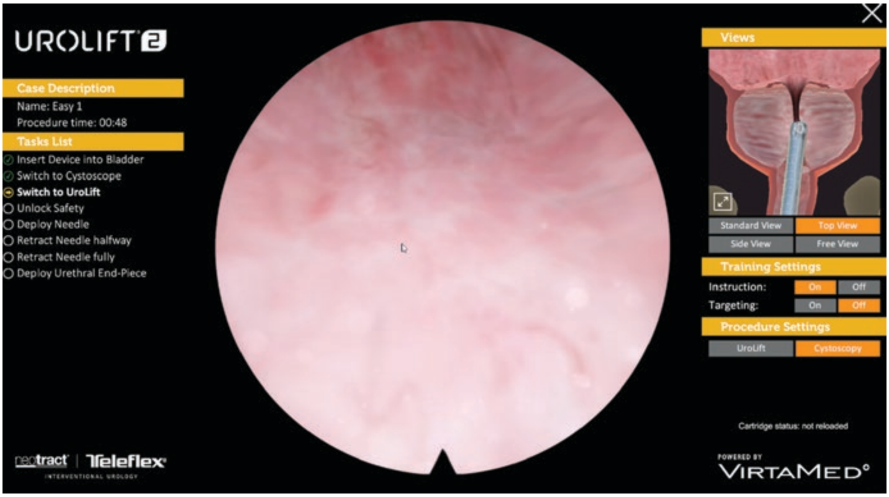

Fig. 11.5 UroLift® Simulator powered by VirtaMed (Reproduced with permission)

Fig. 11.6 UroLift® Simulator powered by VirtaMed (Reproduced with permission)

very expensive. With regard to bench-top models, their cost might be slightly lower, but due to the fact that real surgical equipment is required, their availability will also be limited to the hospital environment. Another issue arising from bench-top models is the availability of materials mimicking real-life physical properties may not be readily available. Another stated limitation associated with TURP simulators is the difficulty to resemble bleeding during procedures.

11.4.4.2 Assessment

Evaluation of surgical ability may be challenging when using many simulators. Due to this, several methods have been designed. One of these is the "The 'Test Objective Competency' (TOCO)–TURBT tool" which was created through cognitive task analysis (CTA) including a group of experts. This tool was created to evaluate surgical preparation, procedure, and completion. The TOCO-TURBT tool was assessed by a panel of eight expert urologists stating that the tool to be feasible, valid, and reliable for the assessment of TURBT competency. The use of CTA could provide a method of evaluation for other procedures serving as a useful tool for future simulators [80]. Another example of a surgical assessment tool is the "Global Assessment of Urological Endoscopic Skills (GAUES)" which evaluates cystoscopy, ureteroscopy, and trans-urethral resection skills. The evaluation of GAUES proved face, content, and construct validity and high reliability, presenting as a powerful tool for future endourological surgical assessment [81].

11.5 Future Directions in Training

Current technological advancements are allowing for improvements in almost all areas of urology. It is therefore no wonder that so many technological advancements are presenting applications that can be integrated into this specialty [82]. Recently, due to improvements in medical simulation, learning through these technologies has become an acceptable method of training and assessment [19, 66, 83–85]. The development of these technologies is mostly related to artificial intelligence; however, the real potential lies behind the possibility for automaticity through machine and deep learning. The following paragraphs include a brief description of these concepts.

11.5.1 Artificial Intelligence

Artificial intelligence (AI) aims to create a machine capable of completing human intellectual tasks. In order to do so, a complex non-linear thought process must be achieved by the machine. In sense, it aims to create reason, thought process, and cognitive function in an entity previously incapable to do so. As we know, the capabilities of humans are broad, with imagination, language processing, memory, and the physiology of other brain functions still not completely understood. The objective of AI is to learn these abilities in order to be able to perform specific tasks. By doing so, AI learning may be performed using previously unseen data without the need to integrate statistical equations for understanding. By elaborating these functions in an external entity, the potential to improve or enhance human thinking is broad [86].

11.5.2 Machine Learning

Machine learning is the process by which algorithms and computer science are used to identify patterns in data. As the quantity of information processed increases, so does the quality of the results. By doing so, the machine becomes capable of generating knowledge [87]. One of the first examples of machine learning is in spam filters for emails, voice and text recognition software, and some Internet web-searchers [86–89]. There are two kinds of machine learning:

- Supervised machine learning: By analyzing vast sequences of input–output data, a pattern to identify outcomes is created. Once this has been established, new data can be analyzed to predict the outcomes based on previous patterns [90].
- Unsupervised: Analyzing data not previously labeled to determine correlations and potential subgroups in which the primary data can be ordered. By doing so, outliers may be identified and extrapolations of general findings may be performed [91].

11.5.3 Deep Learning

Deep learning is considered a subfield of machine learning. It is the uppermost level of this, aiming to reach understanding through a complex neuron-like network. These networks are commonly referred to as artificial neural networks (ANNs). When established, these networks are capable of processing great amounts of data at once.

Through the use of these technologies, improvements in surgical simulators are decreasing the gap between real life and VR, meaning training urologists can improve skills and diminish patient exposure. It is clear that as technology progresses, augmented (AuR) and mixed reality (MR) will progressively become part of the current medical practice [92, 93]. Augmented reality is the combination of images created by computers into the user's view of the real world. Current video games have already begun introducing AR and MR; therefore, it is just a matter of time before these technologies can be extensively adopted in the medical practice

[94]. An interesting example is the Gunner Googles Series. These Goggles with the use of a mobile app enhance learning with AR by incorporating animations, 3D models, and diagrams when studying medical books. Using this technology, learning of otherwise complex topics such as particular anatomies can be facilitated [92].

With regard to intraoperative tutoring, AuR through the use of see-through head-mounted displays (HMD) [94] is the most commonly used training technological tool. Using this technology, users can experience greater immersiveness through the use of holograms, improving spatial awareness. Furthermore, this technology has the ability to be observed simultaneously by many users, allowing for a more efficient teaching [95]. Some limitations may be mentioned, such as the need to carry heavy and uncomfortable devices, battery control, dependence on the Internet connection, and even issues regarding patient security and privacy. Studies performed by Porpiglia et al. evaluated the use of AuR in surgery. They found that the use of their hyper-accuracy 3D reconstruction software integration could diminish complications in robotic-assisted partial nephrectomy and robotic-assisted radical prostatectomy [94, 96].

Other potential applications of AR, such as telemedicine have already been put into practice at conferences around the world. In telemedicine, one surgeon is in the operating room while the other surgeon may be in any location in the world. Using this technology, the expert surgeon may watch the surgery with the possibility of correcting any step. Proximie is a company based in London that has focused on developing this type of technology. Through their technology, they have been able to perform surgical mentoring remotely, allowing for real-time surgical recommendations to be made by drawing on the surgical field [97]. Future urologists will have the possibility to perform surgery using HDM that will aid them during their procedures. For novice surgeons, these surgical aids will decrease the risk and worry associated with procedures during their learning curve as they will have the possibility to access expert recommendations at any given time. The possibilities of these technologies increase greatly when combined with robotic surgery, with the potential to even perform remote surgery [98].

AI has the potential to facilitate the analysis of large series of data, providing an enhancement to medical practice. Furthermore, deep learning can provide reliable predictions, in some cases better than those reached through traditional methods, especially for cases with very large series of data. It is clear that these technologies have the potential to revolutionize clinical practice as we know it, providing fast, reliable, and specific decisions. However, AI requires close quality control through regulation and external validation to ensure the reliability of the results provided. AI systems require new clinical data and continuous training in order to provide the highest quality results.

All these technologies have the potential to enhance the current training and development of surgical skills for urologist trainees. Given the current race for producing the most reliable training software, a wide range of technologies are emerging, creating a perfect era to undergo urology training.

11.6 Conclusion

Numerous training applications are available in urology, ranging from observational to surgical simulators. These offer a wide variety of possibilities for the trainee urologist. We are witnessing how these technologies are taking an active part in medical training as they allow for skill acquisition with decreased patient exposure. Most of these methods of training are now validated by current evidence, further promoting the use of these technologies. By allowing urologists to train in simulated environments, learning curves may be completed without exposing the patient to unnecessary complications. Therefore, there is a possibility for simulated surgical training to reduce complications for certain surgical interventions. Although some simulations have been presented in this chapter, many other surgical interventions still require specific simulated environments in which to train in, as well as their consequent validation. Nevertheless, currently available technology is already creating a paradigm shift in training for urologists, serving as a small insight into what can be expected for future generations.

Key Points

- Simulation-based training in surgery offers many advantages to patients and newly trainees or to experienced surgeons learning new techniques or procedures.
- The most used models for surgical simulation in endourological benign prostatic surgery are bench-top models and computer-assisted virtual reality (VR) simulators.
- There are currently five validated simulators for transurethral resection of the prostate (TURP) surgery, all of which have been validated for content, whereas only four have construct validity and three have face validity.
- With regard to the VR simulator for photoselective vaporization of the prostate (PVP), the GreenLight laser simulator has proved face, content, and construct validity.
- In relation to the Holmium laser enucleation of the prostate (HoLEP) simulators, the UroSim Simulator has been validated for face, content, and construct, whereas the Kansai HoLEP Simulator has the only face and content validity.

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Chapter 12
Simulation in Percutaneous Nephrolithotomy (PCNL)

Jacob M. Patterson

12.1 Introduction

Since the first description of the removal of a renal stone via a percutaneous nephrostomy in 1976 [1], percutaneous nephrolithotomy (PCNL) in its current form was developed in several centers around the world as the first minimally invasive treatment option for large renal stones. Pioneers such as Peter Alken, John Wickham, and Arthur Smith worked with radiological colleagues and other inventors to develop a procedure and associated equipment to allow safe fragmentation and retrieval of stones which would previously have needed major open surgery. When the technique was first described, the idea of percutaneous puncture of the kidney to allow dilatation of a track and subsequent removal of stones was conceptually a big shift from traditional open surgery and represented the beginnings of endourology as a distinct subspecialty.

There are several steps to successful PCNL, including percutaneous needle puncture for access, dilatation of the percutaneous track and placement of a suitably sized sheath into the kidney for the planned procedure, nephroscope introduction and manipulation around the pelvicalyceal system, stone fragmentation and evacuation, and finally placement of drains, stents, etc., at the termination of the procedure. Good percutaneous access is widely regarded as the key to a successful procedure.

As the technology and equipment for PCNL improved with increasing clinical uptake, so did the need and the desire to improve the teaching of the procedure, and in particular for urologists to gain the skills to perform safe percutaneous puncture of the pelvicalyceal system, especially if the technique was to be adopted

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worldwide [2–4]. The requirement for simulation training for PCNL has therefore been around for almost as long as the procedure itself.

Safe percutaneous renal access requires an appreciation of the 3D anatomy of the kidney and its surrounding structures. In addition to planning access through as little parenchyma as possible to reduce the risk of hemorrhage, aiming ideally for a transpapillary access, it is essential that the operating surgeon can be confident that their access will not transgress any adjacent organs such as liver, spleen, colon, pleura, or lung, for obvious reasons. It is also important to have an understanding of how the various viscera move as a result of respiration, and the impact of positioning changes, such as placing the patient in the prone position and the impact or effect of supportive cushions, bolsters, etc., or the impact of the patient being in a supine position where the kidney especially is more mobile under manipulation. Contemporary surgical planning will in most cases involve detailed imaging with computed tomography (CT) scans, but this was not historically always been the case, with many decisions being made on plain radiographs, tomograms, and/or intravenous pyelography. As a consequence of this, initially, there were barriers to urologists' training in an area previously thought to be within the domain of radiology, and many centers adopted an approach whereby a radiologist would gain percutaneous access and subsequently, the urologist would perform the surgical aspect of the procedure. This either happened synchronously or with the placement of a percutaneous nephrostomy catheter as a separate procedure. In some cases, this worked well and continues to do so in many healthcare settings globally with a "team" approach to cases. However, in a lot of circumstances, the access was not well sited in terms of stone clearance, or due to poor working relationships between specialties the service broke down, meaning urologists had to start to learn to perform their own access. Globally, PCNL access is increasingly obtained by urologists with a rising trend toward ultrasound imaging-guided access rather than using fluoroscopy alone.

Initial training for PCNL, like most surgical techniques, followed the traditional Halstedian "see one, do one, teach one" mantra. This is obviously flawed for reasons no doubt covered elsewhere in this book. For PCNL, it has been demonstrated that the learning curve for basic percutaneous access proficiency is around 20 cases, with up to 40-105 cases required to attain expertise or excellence [5–7]. It is therefore highly desirable to have a simulation option which does not place the patient at any undue risk, is repeatable, and ideally without the need for expensive equipment or scarce resources.

Simulation training for most endourological procedures anecdotally started in cadaveric models, which restricted training opportunities to predominantly larger academic institutions, and only in countries where this was available and/or legal. There is, however, very little early published material relating to human cadaveric training for PCNL. It is also described in live anesthetized animal models such as porcine or canine models, but again, these are restricted to a varying degree globally. A huge variety of bench models have been described, some incorporating *ex vivo* animal tissues for a more realistic "feel," and some relying on purely synthetic materials. Recently, 3D printing from genuine patient CT DICOM files has been described to add case-specific details. However, there is a paucity of studies of face, content, construct, and predictive validity for almost all of these simulators, and almost no published evidence to demonstrate their efficacy as educational tools until recently. There is more extensive experience, including validation studies for virtual reality (VR) trainers, but these are associated with very high cost which again limits access for many surgeons in training. It is difficult to design a training model which incorporates adjacent organs and mobile tissues, although a number of attempts have been made. As there is no "gold standard" for PCNL simulation, none of the papers or simulators referenced herein demonstrates evidence of concurrent validity, although one study does compare a new augmented reality simulator to the established 3D Systems PERC Mentor™ showing good criterion validity.

Another major obstacle to the more widespread adoption of simulation training in PCNL is the need for imaging, traditionally in the form of fluoroscopy. Although ultrasound-based models are becoming more desirable, they are still less common than those based on a need for imaging with ionizing radiation. This brings its own risk to the trainee and their supervisor, as well as a need to comply with the ALARA (as low as reasonably achievable) principles [8] and also with variable international laws on ionizing radiation exposure. There is a need to provide both X-ray equipment and appropriate protective equipment for the users, further driving up the costs and reducing the availability of such training opportunities. The use of VR or other software-based options can reduce the need for actual X-ray imaging, but at a cost of reduced realism [9].

In this chapter, I intend to discuss the different simulators available for PCNL access training, as well as covering some aspects of stone treatment and manipulation. Although good evidence exists for the benefits of immersive scenario-based simulation training for improving both technical and non-technical skills for urological surgical procedures, e.g., Transurethral Resection of the Prostate (TURP) and ureteroscopy, there is much less published information on this currently for PCNL training. I will, however, briefly cover some other elements relating to assessment and curriculum design as well, as these have improved recently.

12.2 Simulation for PCNL

12.2.1 Bench Simulators

The simplest ideas are often some of the best, and to a degree, this is true when it comes to simulators and simulation training. Many studies have shown the benefit of, for example, shoebox and webcam trainers for basic laparoscopic skills training, and similar attempts have been made for low-fidelity simulators for PCNL, albeit with less success.

It can make training easier if a procedure can be broken into steps, and there is an argument for simulators to aid each step which trainees can rotate through in turn once achieving competence in the prior step/s. It may be more desirable, however, to have a single simulator which can provide training for the whole procedure without the need to change models or equipment, and to provide a more realistic or even immersive training environment.

Sinha and Krishnamoorthy describe the use of cotton pledgets soaked in contrast media implanted into a vegetable model (a bottle gourd), with the trainees using a puncture needle and a c-arm to get used to the concept of parallax and depth manipulation with 2D imaging of a 3D model [10]. With the exception of the c-arm, this model is extremely low cost and provides a valuable teaching tool for one element of PCNL training, but it does not address the latter stages of the procedure, such as track dilatation, nephroscope manipulation, or stone treatment. Their paper describes a comparison between experts and novices but does not record evidence of skills progression over time, nor any other assessments of the validity of the trainer.

Ex vivo porcine or bovine kidney tissue is one of the most studied models for PCNL simulation, with a number of studies describing a variety of techniques using kidneys and different coverings, including animal skin and subcutaneous tissue, foam, ballistic gel, silicon, or chicken carcasses [11–21]. Some models also incorporated layers of subcutaneous fascia and fat, muscle and segments of the thoracic wall including ribs [22, 23]. All these modifications intend to make the puncture as lifelike as possible while still using cheap materials typically obtained from freshly slaughtered animals, although the possibility of using Thiel-embalmed human cadaveric tissue is discussed by Klein et al. [19].

The main advantage of using biological tissues is that the collecting system of the animal kidney represents a similar structure to the human kidney. By using the attached ureter, a retrograde pyelogram can be performed, or the kidney artificially dilated with saline, to make punctures under fluoroscopy or ultrasound guidance more lifelike. This can be achieved with a retrograde catheter placed before the kidney is embedded in its coverings. The other advantages relate to the similarities between the tissues and “real life” in terms of resistance to the passage of a needle, and manipulation of instruments. This means that all stages of a PCNL procedure can be simulated, although stones have into be artificially introduced to the models if stone treatment elements are to be included [11–15, 17–19, 23, 24].

There are disadvantages with the use of animal tissue. It needs to be kept cold or preserved, to avoid decomposition. New models are therefore required regularly, so they cannot be used for repeated sessions of training. Fully embedding a kidney in a set gel or silicon does improve the tissue longevity [13, 16, 19], but synthetic models will always outlast their biological counterparts. While porcine kidneys are quite similar to human kidneys, bovine kidneys are sufficiently dissimilar to human kidneys that only percutaneous needle access puncture is really feasible; due to narrow infundibulae and differences in calyceal anatomy from the human kidney, it is not possible to perform adequate nephroscope manipulation or stone treatment very easily [20, 24].

Entirely synthetic models also exist for bench PCNL trainers. Bruyère and colleagues described the use of an early form of 3D printing called rapid prototyping [25]. This study involved using case-specific CT DICOM files to produce a layered model of the entire kidney, with void spaces representing the pelvicalyceal system. The model was enclosed within further layers of silicon and also incorporated an inflatable balloon to mimic the effect of diaphragmatic movements related to ventilation to make the challenge of percutaneous puncture more realistic. As this was based on patient-specific scans, it was felt that it may offer the chance for case-specific training preoperatively, which could translate to better performance on an individual patient basis *in vivo,* but this was not reported on. There was also no description of validity of any sort, although face and content validity were alluded to. The model was quite expensive and limited to centers with the equipment to perform rapid prototyping, and it only lasted for a small number of cases before becoming unusable. There are other limitations discussed which could be a focus for future work.

A similar study by Zhang and colleagues with a molded silicon-based reusable model was one of the first designed specifically to address the lack of validity of bench trainers for PCNL. Their model demonstrated good face, content, and construct validity and educational usefulness as well [26]. The criticisms, however, relate to the molded nature of the model, meaning little opportunity for variations of renal anatomy and therefore limited training opportunities.

More recently, 3D printing has become more widely available, quicker, and cheaper. This has then put opportunities for printed training aids closer to a wider range of trainee surgeons worldwide [27]. Veneziano and colleagues in describing their fluoroscopy-free SimPORTAL C-arm trainer [9] utilized a 3D printed pelvicalyceal system embedded within a silicon block, covered with anatomical surface landmarks such as ribs and vertebral column for greater realism. This study was designed to test the c-arm trainer element, but the trainees involved were also studied relative to the percutaneous puncture model, which was effectively an evolution of Bruyère's design. In this study, both the model and the c-arm trainer demonstrated content and face validity. Turney describes another 3D printing technique [28] where, again based on CT data, pelvicalyceal systems are printed using a water-soluble polymer. This is then encased in silicon, then dissolved, leaving a void in the shape of the specific anatomy studied. This allows for a huge variation in renal anatomical models to be used for training and is relatively cheap once the cost of the software and printer is accounted for, but again, the study has no assessment of validity or educational value of the model in question. Again, such models may afford the opportunity to "practice" on a case in a bench setting in the lead up to performing a case "in real life." It remains to be seen if such case-specific training translates into patient benefit, although this is likely to be very hard to demonstrate in a trial setting. Similar hollow 3D printed models have been trialed at the Urology Bootcamp [29] for ureteroscopy, training which has shown early data supporting face and content validity, although this work is not yet complete or published (personal communication, J.M.Patterson and C.S.Biyani).

Rawandale and Patni designed a low-cost ultrasound-guided renal puncture simulator with ultrasound compatible medium, organ dummies, and a mannequin (Fig. 12.1). It allows ultrasound-guided puncture and saline aspiration. They evaluated face and content validity with 16 trainees and two experts [30]. They reported

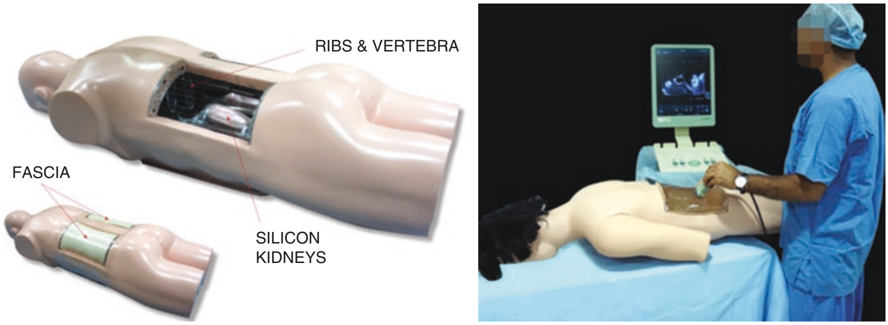

Fig. 12.1 Ultrasound guided renal puncture simulator

Fig. 12.2 Fluoroscopic guided calyceal puncture simulator

statistically significant improvement in their Global Rating Scale scores, total procedure time, fluoroscopic time, and attempted needle punctures. In addition, the same group has also developed a portable fluoroscopy-compatible simulator using CAD software (Fig. 12.2) [31]. The simulator allows practice with the standard PCNL instruments, replicates natural tissue-haptics, and has various error alarms. It also mimics respiratory movements and a regular endoscope can be used to confirm successful puncture from within the synthetic kidney. These studies and devices have been presented in a number of abstracts, but have yet to be published and further results are awaited with interest.

Some other promising synthetic bench models are described, but not yet reported in peer-reviewed literature. There is some early testing underway through training programs such as the hands-on training courses run by the European Association of Urology's European School of Urology, and the Urology Bootcamp simulation training program in the UK [29]. These courses have used devices like the PCNL BOX from Encoris (https://www.encoris.com/pcnl-kidney-trainer/), and the PCNL LS40 trainer from Samed (https://samed-dresden.com/pcnl-trainer/). Both allow ultrasound-guided access, as well as being compatible with CT and fluoroscopy

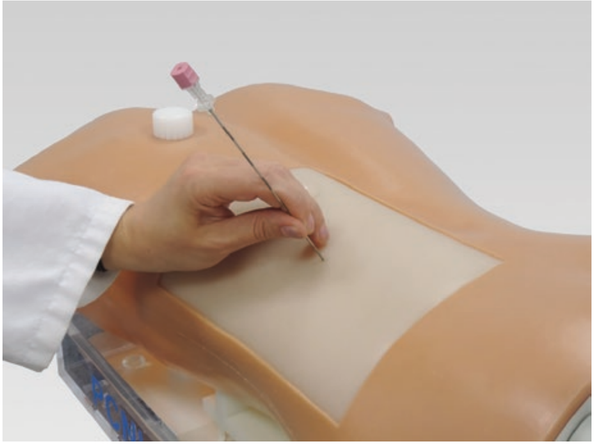

Fig. 12.3 The SAMED LS40 PCNL simulator (Photo courtesy of SAMED, with permission)

imaging, and have interchangeable kidney modules allowing for variation in renal anatomy and stone size/position, etc. Both are able to support all steps of PCNL surgery, from access to closure [32]. Validation data on construct and content validity are eagerly awaited. Face validity of the Samed LS40 PCNL trainer was confirmed with a review by the faculty of the Urology Bootcamp in the UK (personal communication, J.M.Patterson and C.S.Biyani 2019). The Samed trainer is shown in Fig. 12.3.

12.2.2 Live Animal Models

The opportunity for "wet-lab" training on anesthetized animals has been shown to provide the training experience most similar to surgery in humans. With perfused vascularized tissues, there are problems such as managing intraoperative bleeding and other complications which are much harder to emulate in any other environment. In the case of PCNL training, the kidney will move with respiration. This is very hard to simulate in a realistic fashion in a synthetic or *ex vivo* biological model. With living tissue, the haptic feedback from instruments is far superior to any virtual reality system. There are ongoing ethical debates about the appropriateness of animal testing of this sort, which are not the focus of discussions in this chapter, but they cannot be ignored. Furthermore, not all countries permit surgical training on live animals, further limiting opportunities. It is a costly process, and each model cannot be used indefinitely. There is a requirement for veterinarian support in addition, and specific ethical requirements peculiar to individual countries. The pig model is probably the most studied for urological procedures, due to the anatomical similarity between the two species and from the perspective of PCNL training, the similarity of the renal anatomy.

Those models that are described include Kallidonis et al. and their description of using a porcine wet-lab model as part of their PCNL modular training system [33]. The details of training in the anesthetized pig are limited in the paper, and there is no validation of the model as the benefit of wet-lab training is simply extrapolated from experience in other fields such as laparoscopy.

Mishra et al. describe the use of a porcine model to assess the validity of a VR simulator [34], with some of the trainees involved participating in pre-training and post-training attempts at percutaneous needle access in an anesthetized pig model to show the predictive validity of the VR model, rather than any specific assessments of the validity of the animal model itself for training, which again seems to be assumed in the text. They do comment specifically that their validation of the VR trainer implies that VR simulation training would be best employed before any training in an animal model to reduce the cost, relatively, and maximize the educational benefit of using animals in this way. The same authors did demonstrate the content validity of the pig model in another paper comparing it with the VR model [35].

Overall, there is little published on the use of animal models for PCNL simulation or the validity of this model from an educational perspective, so it is difficult to make further recommendations on this matter.

12.2.3 Cadaveric Models

Surgical training utilizing human cadavers is not new. From the earliest descriptions of anatomical teaching in the theaters at Padua to the contemporary teaching of medical students in the twenty-first century, cadavers have been used to demonstrate anatomy and pathology. Dissection of human cadavers is an introduction to surgical techniques for most undergraduate students, as well as teaching one of the fundamentals of medical practice. When it comes to simulation training, specifically training for PCNL, there is very little published evidence. However, there are published papers describing cadaveric studies on PCNL-related renal injuries [36], and assessment of renovascular anatomy for a safer percutaneous puncture [37], but only a single study of using human cadavers as a specific simulation setting for PCNL training [38]. In this study, the authors describe the use of Thiel-embalmed cadavers, rather than the more widespread formalin-embalmed or fresh-frozen cadavers, specifically addressing their suitability for PCNL training with a focus on ultrasound-guided access. Thiel-embalmed cadavers have been shown in other fields, such as endoscopic urology and laparoscopic surgery, to be more life-like, with more supple tissues, and better preservation of natural tissue color differentiation. In addition, they are not associated with the same problems relating to odor that afflict other types of cadaver [39]. One shortcoming of any cadaveric model is that it is not usually possible to assess stone treatment techniques, as stones are not usually present. Small stones can be introduced via the percutaneous access track, or larger stones can be placed via separate abdominal open surgical access, but this makes the process much more complex and risks further problems such as leakage of fluid from the pelvicalyceal system and subsequent failure of hydrodistension, making puncture more challenging.

In their study of USS-guided PCNL access utilizing Thiel-embalmed cadavers [38], Veys and colleagues showed good face and content validity of their model for both initial and advanced PCNL access training. It was more challenging to incise/puncture the skin than in living patients, but all other aspects of the model were realistic. Thiel-embalmed cadavers appear to provide a very lifelike simulator for ultrasound-guided access, which shows key promise in reducing radiation risk to trainees and trainers alike. The tissues of the pelvicalyceal system were noted to be paler, but this did not compromise the training experience. The authors performed endoscopic combined intrarenal surgery (ECIRS) meaning retrograde ureteroscopy was performed in the cadavers in addition to PCNL access, but the validity of the model for this aspect of the training was not assessed.

There are no reported cadaveric studies looking at any aspects of nephroscope manipulation or other components of the PCNL procedure, nor are there studies validating the training in terms of predictive or construct validity. More studies are certainly needed on the reliability of cadaveric models and ideally bigger studies which can reliably estimate costs and benefits to see how viable this form of training can be.

12.2.4 Virtual Reality Trainers

While VR has developed exponentially in recent years with advances in computer processing power, many homes now have recreational VR headsets for use with smartphones and gaming consoles, whereas 25 years ago VR was almost seen as a military-only technology. Simulation training as an entity started in the military and subsequently, in particular in commercial aviation, as the benefits were clear in terms of accruing hours of experience without risking expensive machinery or people's lives, and flight simulation has been the mainstay of pilot training for decades. Similar benefits would soon be demonstrated in training for surgical procedures through deliberate practice and simulation of procedures and techniques.

As the technology has developed, so have the potential uses of VR. In urology training, there are VR simulators for cystoscopy, transurethral resection, myriad procedures for BPH, ureteroscopy, and PCNL, as well as increasingly for laparoscopic and robotic surgical procedures [40].

The most widely reported simulator for PCNL access and procedural training is the PERC Mentor™ (3D systems, USA—formerly Symbionix, Figs. 12.4 and 12.5). This is available worldwide, but adoption of the system as a training tool is limited by its cost, of up to US$100000, with maintenance and software considerations as well. It is not possible to use the device for ultrasound-guided access, or hybrid access techniques involving ultrasound, which is a further limitation. The final criticism is the lack of haptic feedback provided by most VR models compared with animal models or patient tissues. The PERC Mentor™ consists of a prone flank

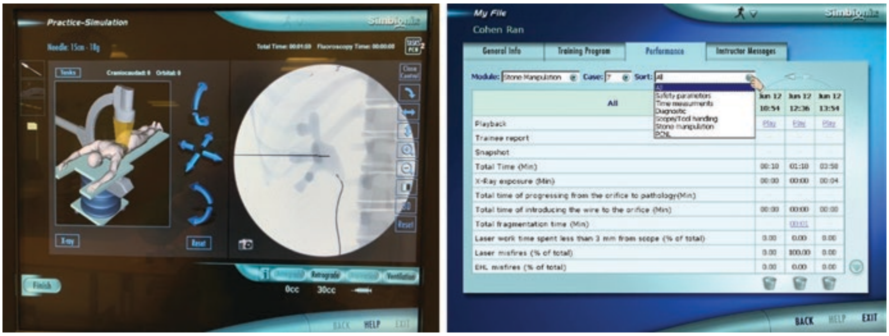

Fig. 12.4 The 3D systems PERC Mentor™ Screenshot with performance matrix

Fig. 12.5 3D systems PERC Mentor™ Virtual patient torso with a variable abdominal wall thickness

model which can be punctured, coupled with a computer interface which is able to simulate differing anatomical constructs and additional elements such as pyelography and respiratory movements during puncture. It is able to simulate track dilatation methods and nephroscopic procedures, including simulated stone treatment or arcade-style games designed to test the students' ability to navigate the pelvicalyceal system to predefined targets. Due to the nature of the computer interface, movement details, procedure timings, and number and types of errors made are recorded and can be translated into a large array of numeric outputs. This means that the device can show progression within an individual student, as well as differentiating between novices and experts based against an internal gold standard. This all sounds very promising, but these VR simulators are not without problems. They can be frustrating when the software and hardware do not perform perfectly together, they have some idiosyncrasies which make them challenging to work with, and they are on occasion prone to software "bugs" and glitches which can be frustrating for the user.

Noureldin and colleagues have published extensively on simulation in urology, including training options for PCNL. In one paper on the PERC Mentor™, they describe the utility of the tool in training postgraduate urology trainees in percutaneous access [41], demonstrating excellent construct validity in the process. This was repeated in a different cohort with the same results, implying reliability and educational value [42].

In one of the earliest published reports of the PERC Mentor™, Knudsen and colleagues demonstrated the good face, content and construct validity of the simulator in training inexperienced urologists to perform PCNL, as judged against the modular Global Rating Scale (GRS) assessment tool for PCNL [43].

As mentioned in the section on animal wet-lab training, Mishra et al. reported primarily on the validity of the PERC Mentor™ in their cohort, some of whom also underwent training in the animal model [34]. In this study involving both experts and novices, they successfully demonstrated face, content, construct, and predictive validity, as well as educational value. The study used metrics from the simulator in addition to the GRS as used by many of the other studies, including Knudsen et al. above. The same authors also described the content validity of both elements of their training program, including the pig model, in another paper [35].

In another study of the impact and efficacy of using the PERC Mentor™ as a training tool, Zhang and colleagues demonstrated again that the device has construct validity and is a useful adjunct to traditional training [44]. Following this theme, Papatsoris et al. again demonstrated the good construct validity of the PERC Mentor™ in a cohort of UK Specialist Registrar Urology trainees [45]. They used one of the additional beneficial aspects of this particular simulator to demonstrate this, showing that simulated radiation exposure was reduced with experience on the simulator. As no actual X-rays are produced by the simulator and fluoroscopy being purely computer-generated, none of the trainees or faculty will have encountered any additional radiation exposure. This is an understated benefit of VR training.

One other interesting study presented the initial experience with a different VR simulator, the Marion Surgical K181 [46]. This differs from the PERC Mentor™ in that it provides haptic feedback through the use of motorized devices to provide resistance and feedback to the user. It is also a much more immersive simulator than the PERC Mentor™, placing the trainee in a VR operating theater environment with simulated fluoroscopy and including elements such as stone treatment and removal, as well as percutaneous puncture, all involving haptics. Sainsbury et al. showed the Marion Surgical K181 demonstrates face and construct validity, and larger trials are awaited, which will hopefully show predictive validity and educational reliability. One of the details in this study is the description of how VR tools are able to generate metrics such as tool path length, or the distance the tip of an instrument travels in the course of performing a specific maneuver. This correlates well to expertise and economy of movement studies support this. This can therefore aid in the demonstration of a simulator's construct validity. Tools and metrics like this are the key attractions of VR simulators, as they allow repetition of specific tasks and recording of specific associated metrics, which allow the individual to track their progress and, hopefully, show progression toward competence. The same tools can be applied to experts to further develop their technique, and in the future, it may be possible to use patient-specific imaging to produce a VR construct of that patient for rehearsal in VR before proceeding to an actual procedure.

12.2.5 Immersive Training

Ghazi and colleagues describe a novel synthetic simulator, created through an iterative process of repeated bench testing of different polymers and synthetic tissues until the model was sufficiently similar to cadaveric or animal tissue [47]. They then undertook an immersive simulation process with both novices and experts in a simulated operating theater environment to better re-create a realistic environment in which to evaluate performance. The description of this immersive environment is somewhat lacking in detail in their text, but it does include post-procedural debriefing, which is an important factor in contemporary educational activity of this sort. The model and training environment demonstrated good face, content, and construct validity. This model also provided an opportunity to demonstrate validity for procedures relating to stone treatment as well as percutaneous access alone, which also sets it apart from other work.

The study described above by Sainsbury and colleagues is also an example of the improved realism of a simulation when immersive VR is used in addition to computer-generated images [46].

Brewin and colleagues describe the use of a distributed simulation environment in the assessment of training in TURP procedures [48]. This environment represents a portable simulated operating theater, in which simulators of differing types can be studied, and is more readily available than an entire operating theater set aside for training maneuvers only, which obviously comes at great cost. This training "igloo" provides a much more realistic and immersive environment where a combination of technical and non-technical skills can be assessed in parallel. Although none has yet been published for PCNL training, this sort of training experience can only augment the quality of the training in the models mentioned above.

Tai and colleagues recently published their experience of a novel simulator based entirely in augmented reality. (AR) [49] The system comprises a PC linked to two haptic devices, acting as phantoms. One represents the puncture needle, using a hand-held stylus, and the other represents palpable anatomic landmarks such as ribs, pelvic bones, etc. The trainee uses a VR headset which generates a visual and auditory representation of an operating theater to present a fully immersive simulation. The PC generates case-specific images based on CT DICOM files of actual patients, which feed into the patient construct seen by the trainee. There is no physical "patient" for the "needle" to puncture, with all tactile sensations delivered by the haptic devices. In this initial presentation of their work, the authors describe good face, content, and construct validity, as well as what they describe as criterion validity in comparison with PERC Mentor™. There is an even greater range of data generated, which is all numerical and therefore easy for the trainee to see progress, as well as allowing good discrimination between experts and novices. The system described also appears cheaper than PERC Mentor™ but is not widely available. This sort of system, however, may present many more opportunities in the future as such devices become more readily available. Ideally, it would evolve such that easier methods of uploading local information would allow use of local patient data, allowing surgeons to prepare for upcoming cases as well as training.

12.2.6 Model Summary

The models and simulators that have had some assessment of their validity in any way are summarized in the Table 12.1, with an idea of the cost-effectiveness of the model described. Most papers present a low level of evidence, but there are a small number of randomized trials and longitudinal studies of the impact of simulation training are anticipated in time.

Table 12.1 Summary of evidence for PCNL simulators

		Validity				Reliability	Cost
Paper	Type of simulator	Face	Content	Construct	Predictive		
Sinha [10]	Vegetable model			✓			±
Klein [19]	Porcine kidney in ballistic gel	✓	✓	✓		✓	++
Vijaykumar [21]	Bovine kidney in chicken carcass		✓	✓		✓	+
Mishra [35]	Live porcine model (and VR simulator)		✓				+++
Zhang [26]	Molded synthetic silicone	✓	✓	✓		✓	++
Ghazi [47]	3D printed silicone, immersive training	✓	✓	✓		✓	+++
Veys [38]	Thiel-embalmed cadaver	✓	✓				+++
Noureldin [41]	PERC Mentor™ VR			✓	✓		+++++
Knudsen [43]	PERC Mentor™ VR	✓	✓	✓		✓	+++++
Mishra [34]	PERC Mentor™ VR (and live porcine model)	✓	✓	✓	✓	✓	+++++
Sainsbury [46]	Marian surgical K181 VR	✓		✓			+++++
Tai [49]	Augmented reality AR	✓	✓	✓	✓	✓	++++

12.2.7 Intraoperative Assistance

In addition to the simulators described above, which to a varying degree may prepare the trainee surgeon for cases on patients, there are also described additional training aids which may further simplify percutaneous access when finally facing a real case in the operating theater environment.

Rassweiler and colleagues describe the use of fiducial markers and fusion imaging to generate a 3D image of the kidney, the stone and surrounding structures, which can be used to target the best access point with the aid of the image displayed on an iPad or computer monitor. Although this appears to provide some reassurance to the surgeon, there is no clear benefit in terms of speedier access, or reduced radiation dose, in matched-pair analysis. Although this work is promising, it is yet to be seen how it may benefit clinical practice [50, 51]. This technique was also used in a validation study of a bench-top model, where it also failed to yield much benefits, but did help to confirm the face, content and construct validity of their porcine kidneys in ballistic gel bench model [19].

Other augmented reality technologies have been tested in Urology [52], but few related to PCNL. Devices such as the HoloLens, or other VR headsets may allow better use of patient images which are otherwise static bystanders in the operating theater. In the future, there may be an opportunity to overlay 3D CT images on the operative field, for example, tracking needle position and instrument movements necessary to successfully and safely puncture the kidney and perform PCNL. At the time of writing, such techniques have yet to be described for endourological procedures.

One of the difficulties for the novice surgeon in the operating theater is fine manipulations of the percutaneous puncture needle in the face of respiratory movements and also the issue of the surgeon's hand often finding itself straying into the path of the image intensifier, thus exposing the surgeon to unnecessary ionizing radiation from X-rays [8]. This is especially true when employing a "bullseye" or "eye of the needle" technique for end-on calyceal puncture. It is not uncommon to see trainers trying to demonstrate the use of an artery forceps or needle holder to remove the surgeon from the X-ray field, but Lazarus and Williams describe a novel device (The Locator) to act as a needle holder and guide specifically for this purpose [53]. This showed good stabilization of the needle and a reduced radiation dose, but conferred no other specific advantages compared to free-hand puncture.

While robotic systems seem to be at the forefront of contemporary urology, the use of robotic assistance for percutaneous puncture for PCNL has never really taken off. Pollock and colleagues describe two systems which were tested for efficiency and accuracy at automated needle puncture [54]. The better of these systems was the AcuBot system, which was fast and accurate at identifying and puncturing onto fiducial markers within a gelatin-filled phantom. This is, however, a complex and somewhat unwieldy system, and most importantly, it is prohibitively expensive, meaning adoption has not taken off on a global scale. More interestingly, and with growing global interest in remote control of robotic systems, or telerobotics, colleagues at

Guys' Hospital in London and Johns Hopkins in Baltimore describe the first trial of transatlantic telerobotic-controlled percutaneous puncture, using the PAKY-RCM robot [55, 56]. This robot was developed to automate the process of percutaneous puncture and performed well against human comparators in a phantom model, albeit slightly slower, but again has not been adopted worldwide because of cost, and problems automating some elements, such as the response to renal and surrounding tissues to respiration and bending of the puncture needle, which the human controlling the needle can seemingly control much better. Incidentally, the phantom model used in the study has not been tested or validated in any published work either.

In summary, although attempts have been made to further assist surgeons on their learning curve, there has not been anything really of note which aids in the operating theater, emphasizing the key importance of prior simulation experience. The exception to this is specific training in ultrasound skills, which gives the surgeon more options in terms of access than fluoroscopy-guided access alone, and radiology training in ultrasound has utilized such models for some time [57].

12.2.8 Training Curricula in PCNL

The educational methods for surgical training continue to evolve and develop. As we have moved on from Halsted into more rigorous assessments of competence and capability, so the surgical training programs and simulation training in particular have had to adapt and be more robust under scrutiny.

Mishra and colleagues identified a need for a different approach to PCNL training in their review in 2013. This highlighted the need for knowledge as well as skills training, and advocated a combination of dry-lab and wet-lab training models to improve skills before going into clinical hands-on training [58]. In 2015, Kallidonis and colleagues report on the initial validation of a modular training curriculum applied to two trainees. This showed progression through key skills toward independent practice, but most of this training was in a clinical setting, with only the first module being in an animal model. This only included two trainees and is therefore hard to validate [33].

The team at King's Hospital in London have been at the fore of simulation training in the UK and worldwide practice, developing curricula for both technical and non-technical skills. Quirke and colleagues have recently published their paper outlining the development and content validation of a PCNL assessment score, which can be used to benchmark and assess trainees' progress through the steps required to become proficient in PCNL [59]. It builds on historical rating scales as used in many of the other papers included in this review, such as the GRS for PCNL [34, 43].

This important step in defining the required steps of the PCNL procedure in more detail will hopefully pave the way for a standardized approach to teaching and assessing progress, and can also be used to assess the usefulness of simulators and procedural skill acquisition, as well as key non-technical skills required to achieve competence, independence, and ultimately excellence.

12.3 Summary

Although a large variety of increasingly complex simulators have been described for PCNL training, there is little high-quality evidence to support the educational validity of these simulators. Few of the low-cost simulators have adequate assessment of face, construct, or content validity, and there are few papers describing how these simulators can be used to improve on traditional methods of surgical training. The most extensive evidence is for the PERC Mentor™ virtual reality simulator, but the cost of the device and its maintenance are prohibitive for most training environments. There is a need for high-quality, low-cost simulators with demonstrated face, content, construct, and predictive validity, which can be used globally with ultrasound and/or simulated fluoroscopy to support PCNL training in the future.

There is also a need for validation studies demonstrating the benefits of exposure to simulation training in percutaneous procedures, translating into improved performance in an operating theater setting, or even improved patient outcomes, as well as validation of specific tools.

Key Points

- The educational value of simulators for PCNL is unproven in many cases.
- VR and AR provide a lower level of risk for trainees and trainers due to ability to simulate X-rays without ionizing radiation exposure, but are invariably significantly more expensive and much less available globally.
- A hybrid of cheap bench simulators and more immersive simulations will potentially deliver the best balance of cost, availability, and efficacy. There is a need for low-cost, high-quality simulators with good validity, ideally offering options for ultrasound- and fluoroscopy-guided percutaneous access training.
- Curricula for PCNL training in a simulation setting will help standardize the requirements for trainees and trainers alike.

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Chapter 13
Simulation in Functional Urology

Dirk De Ridder and Chandra Shekhar Biyani

13.1 Introduction

While simulation models have found their way into many training curricula in urology, especially in laparoscopic and endourological or robotic approaches, their use in functional urology is much less prevalent. The training models and curriculum are sub-optimally standardized in urogynecology. The urogynecology subspecialty, in this regard, faces challenges in the design and development of "appropriate" training content for specialists who express special interest. A survey found that 54% of recent graduates rated their urogynecology experience as satisfactory [1]. In another survey conducted in Germany, 336 urological residents and 190 chief physicians were appraoched, as well as 171 gynecological residents and 175 chief physicians. Of all trainees, 70.0% stated a personal interest in Urogynecology, but 45.4% (gynecological residents) and 52.9% (urological residents) indicated a lack of standardized training in their own department [2].

The complex anatomy of the female pelvic floor with few bony surgical landmarks and the fact that this anatomy can change considerably in a woman's lifetime adds to the difficulty of implementing simulation models in female reconstructive urology. While at a young age, the muscular components of the pelvic floor and the supporting fasciae might be more or less easy to identify, the structures will deteriorate in the case of vaginal prolapse or urinary incontinence. The pelvic floor can

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undergo several changes with advancing age: avulsion of one or both arms of the levator arc, elongation of cardinal, sacro-uterine ligaments, positional changes of the uterus, fibroma formation, cystocoele and rectocoele formation, and scar tissue from previous surgeries. Teaching surgical approaches on the basis of models mimicking normal anatomy does not make sense if surgeons thereafter need to operate on distorted anatomical findings in real-life patients.

Despite this, several attempts have been made to construct simulation models to increase the knowledge of anatomy and to prepare the surgeon's minds and hands before embarking on reconstructive surgery to gain insight into the pathological changes of the pelvic floor and pelvic organs. There is certainly a need for more simulation-based training since the recent survey of the European Association of Urology showed that most training centers do not have a dedicated training center or simulation center for laparoscopy, robotics, urological procedures, and the use of lasers. The survey does not even mention functional urology simulation models [3].

One of the motivations behind having a subspecialty is to acquire knowledge, specialize and develop expertise, and to achieve it would require well-structured and harmonized urogynecological education and training along with interdisciplinary cooperation. In this chapter, we present the "art of urogynaecology simulation" and hope that a broad-based, well-designed training network and curricula should be established and used regularly.

13.2 Models for Pelvic Floor Anatomy and Surgery

13.2.1 Pelvic Examination

The female pelvic examination has long been considered a fundamental component of the assessment of the internal and external pelvic organs. Female pelvic examination teaching and training poses real challenges for trainees in urology. The intimate nature of the examination, time pressures faced in the clinical setting, and patient expectations all contribute to limited opportunities to learn the skill. A systematic review reported a significant benefit with a pooled effect size of 1.18 (95% CI 0.40–1.96; $p = 0.003$) comparing simulation training for pelvic examination with no intervention, and concluded that training in pelvic examination with technology-enhanced simulation is associated with moderate to large gains in performance, in comparison with no intervention [4]. Clinical Female Pelvic Trainer (CFPT) Mk 3 (Limbs and Things, UK) contains 7 different pathologies (1) normal female pelvis with an anteverted uterus; (2) normal female pelvis with retroverted uterus; (3) uterus with a small fibroid and a cervical polyp; (4) large fibroid uterus and cervical ectropion; (5) generally enlarged uterus equivalent to 10 weeks of gestation; (6) generally enlarged uterus equivalent to 16 weeks of gestation; and (7) ovarian cyst (Fig. 13.1). The model was evaluated by 26 novices and 24 experts for realism and

Fig. 13.1 Clinical Female Pelvic Trainer by Limbs and Things (Reproduced with permission)

construct validity [5]. In another study, 72 interns were randomized and underwent baseline skills assessment. Seventy interns returned for follow-up assessment after approximately 14 weeks (range, 10–17 weeks). They showed that a training program for interns improved skills essential in the performance of pelvic examinations, and that improvement was apparent 3 months after training [6].

13.2.2 Imaging as the Basis for Training Models

Imagining 3D anatomy based on representations in 2D textbooks and slides is a challenge for many medical students. Cadaver dissection during the medical curriculum is often the first possibility for students to feel and touch the 3D structures in reality. In surgical training, cadaver dissections still have a place, but they are expensive and the embalming procedures distort the anatomy. Moreover, the stiffness of the embalmed tissue does not in any way resemble the flexibility of real tissue. Cadaveric anatomy mostly represents normal anatomical structures, while reconstructive pelvic floor surgery mostly deals with abnormal anatomical structures (such as prolapse). Therefore, imaging is being used for illustrating anatomical changes and can also serve as a basis for surgical training models.

For many years, colpocystodefaecography was the gold standard for pelvic floor imaging in cases of prolapse. This procedure, which is performed in a sitting position, mimics the pelvic floor descent in a realistic way. The increased use of MRI as an imaging modality has led to a shift toward MRI imaging of the pelvic floor. Since these MRI's are being performed in a supine position, the correlation with the real pelvic floor descent has been weakened. When compared with CCD, supine dynamic MRI is unreliable, especially in the anterior and middle compartments. Even in the detection of enterocoeles, CCD was superior to MRI. In general, the best results with MRI can be expected for evaluation of the rectum, but we have to keep in mind that we usually underestimate the pelvic organ prolapse in the supine position [7, 8].

Some authors used clay models of the pelvic floor in the training of obstetrics and gynecology residents. A study comparing different groups using clay models and just receiving classical anatomical lectures showed a significant difference in the test in favor of those using the clay models [9].

It seems to be important that students can feel and touch the anatomical structures since a study using a CD-ROM interactive approach compared to traditional paper-based methods, did not show an improvement in the retention of anatomical knowledge [10]. Other studies have shown as well that 3D reconstructed models were useful, despite the small number of participants [11].

A controlled trial in undergraduate students comparing the effectiveness of (1) a virtual reality (VR) computer-based module, (2) a static computer-based module providing Key Views (KV), (3) and a plastic model showed that there was no difference between the groups. Computer-based learning resources appear to have significant disadvantages compared to traditional specimens in learning nominal anatomy. Virtual reality showed no advantage over static presentations [12].

Despite these initial disappointing results, a recent systematic review by Boff et al. on anatomy learning concluded that the use of smartphones, rapid response codes (QR), virtual reality (VR), three-dimensional printed modalities (3DP), 3D prostheses, and other technologies benefited students in anatomical learning. These technologies have proven to be effective in teaching human anatomy, given that most studies have proven their enriching potential in assessments.

13.2.3 Cadaveric Models

Pelvic floor reconstructive surgery has been popularized during the vaginal mesh era, when many gynecologists and urologists embarked on this type of surgery, which became more accessible and easier to perform thanks to the use of the so-called mesh kits [13–15]. These kits lead to more complications than other approaches. This is probably one of the reasons being that a thorough understanding and sufficient surgical experience with the complicated pelvic floor anatomy was not required for using these kits.

Pelvitrainers and animal models were used to increase the practice level of the interested surgeons, but these models have limitations because of the differences in tissue handling. The use of human cadavers was also limited by the classic formaldehyde preservation methods that made the tissue rigid and discolored. Frozen cadavers were not ideal either. Thiel developed a new embalming method that allowed passive joint mobility while maintaining the muscle and fascia color and offered tissue flexibility and plasticity. These advantages led to a wide adaption not only in the field of anatomy teaching, but also in surgical (laparoscopic and endoscopic) training [16]. A prospective observational study in pelvic and perineal surgical postgraduate training showed the superiority of this embalming method over other modalities regarding gaining confidence and precision in surgical skills [17].

13.2.4 Low-Cost Models

Training models using cadavers, expensive 3D prints, or VR simulators are often too expensive for low-resource environments. However, declining rates of vaginal procedures as well reduced opportunities for practice due to the increased presence of multiple trainees, restricted working hours, and the intrinsic low visibility while observing vaginal procedures have forced trainers to supplement their teachings with high- and low-fidelity surgical models. The creativity and ingenuity of the surgical trainers in these settings have led to low-cost models. Gupta et al. (2018) published the development of a Le Fort Partial Colpocleisis model to treat procidentia, using felt and Velcro [18]. The model's cost was under $14 and the making time was <1 h. The video is available online (https://players.brightcove.net/4988507115001/BJ5hvqqbQ_default/index.html?videoId=ref:sj-vid-1-mde-10.1177_2382120518801582).

Kisby et al. [19] adapted a vaginal hysterectomy model to teach apical suspension techniques. They used heat shrinking tubing to mimic the uterosacral ligament, hosiery and Velcro to simulate the vaginal cuff and peritoneum, and an L-shaped PVC pipe to replicate the vaginal and introitus (https://link.springer.com/article/10.1007/s00192-019-03985-y#Sec3).

Urethral bulking agents—endoscopic injection of urethral bulking agents is a well-established procedure to treat stress urinary incontinence. Farhan et al. used a female porcine bladder and mounted it on a hysteroscopy diagnostic trainer [20]. A total of 12 participants using the standard endoscopic equipment assessed the face and content validity. The authors reported good face and content validity (experts 3.9/5; novices 3.8/5). The construct validity showed a better rating in all categories of the procedure by the experts (4.1/5). A successful use of the model at the national urology boot camp has been reported (Fig. 13.2) [21].

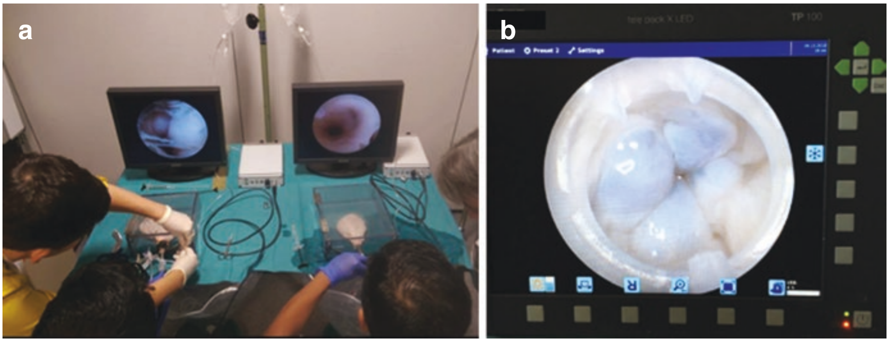

Fig. 13.2 Porcine bladder set up for the urethral bulking procedure (**a**), post-procedure endoscopic view (**b**) (Courtesy Urology Simulation Boot Camp, Medical Education Dept, St James's University Hospital, Leeds, UK)

13.2.5 Virtual Models

The use of virtual reality has not been extensively studied in the field of functional urology. It has been evaluated in an RCT, randomizing 31 obstetrics-gynecology residents. One group received a traditional pelvic floor anatomy course, while the other group was offered a virtual model (Viscube SX VR, VisBox, Inc., Saint Joseph, IL, USA) on top of the traditional course. This immersive simulation showed no significant improvement in the post-test scores, although the majority of the VR exposed residents believed that the VR experience would improve their knowledge of female pelvic anatomy and their future patient care [22]. A virtual reality simulator (Pelvic Mentor®) has been developed by 3D Systems (formerly Simbionix). It is an integrated hybrid system (physical mannequin and a computerized 3D virtual system). The simulator allows a trainee to place sensors on his or her fingers with the mannequin and the 3D pictures provide a real-time indication of finger palpation of the pelvic organs. The simulator allows a dynamic review of pelvic muscles, organs, bones, ligaments, and blood vessels, including pathological pelvic anatomy. Legendre et al. performed a study to assess the knowledge of pelvic-perineal anatomy of eight residents in the Obstetrics and Gynecology Department. They demonstrated significant improvement in internal rating with a proportion of structures identified from 31.25 to 87.5% ($p < 0.001$) for the anterior compartment and 20 to 85% ($p < 0.001$) for the posterior compartment [23].

Transurethral injection of botulinum toxin (Botox) into the inner bladder wall has emerged as an alternative and second-line treatment option for patients with an overactive bladder. Training new residents and nurse specialists in this highly successful technique remains a challenge. A study used the ETXY Multifunctional Trainer (Pro-Delphus, Brazil) and demonstrated good face and content validity [24]. A total of 56 participants trained by 14 experts performed more than 50 procedures on the simulator. Participants reported significant improvement in their skills (mean: 4.02/5) and acquired transferrable skills (mean: 3.95). In addition, a significant proportion recommended that the model should be used for training and assessment (4.14/5). Experts' responses to the realism of the model were as follows: anatomical details (mean: 3.62), cystoscopy (mean: 3.62), needle penetration (mean: 3.31), and injection delivery (mean: 3.69) on a Likert scale. Virtual reality-based Botox® injection into the detrusor muscle of the bladder has been developed by Touch of Life Technologies (ToLTech, Colorado, USA) [25]. Young et al. have reported good learning outcomes with the simulator (Fig. 13.3) [26].

13.2.6 3D Printing

The use of 3D printed simulation models relies on 2D imaging datasets that are modeled into 3D visualizations. Data management, simulation, and printing itself are error-prone steps that need to be taken with care [27]. Despite these technical

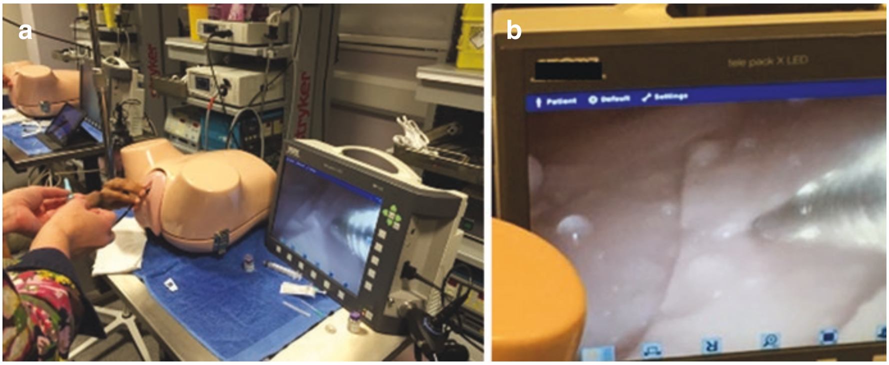

Fig. 13.3 VR Botox simulator (**a**), simulation of injection into the detrusor muscle (**b**) (Courtesy Urology Simulation Boot Camp, Medical Education Dept, St James's University Hospital, Leeds, UK)

hurdles, progress is being made. A sacral neuromodulation model for surgical training seems to be as reliable as a cadaveric model [28]. A 3D model constructed on the basis of 30 CT scans, could predict some anatomical landmarks that would increase the safety of laparoscopic sacrocolpopexy [29]. This might be interesting, but averaging the anatomical landmarks of 30 women is far from using 3D models in individual surgical planning for an individual patient. The treatment of complex prolapse problems, such as in recurrent or cases with complications from mesh surgery, could be improved using pre-operative 3D models or 3D printed models. But before we can use this technology, further studies on imaging and modeling will be needed [30, 31].

13.3 Summary

The field of simulation in functional urology is evolving rapidly but is struggling with the intrinsic variability of the female pelvis throughout the stages of life; the pelvic anatomy of a nullipara at 25 years old is not the same as that of a 70-year old multipara post-menopausal woman with multicompartmental prolapse. In the case of prolapse, the pelvic organs will undergo dynamic changes with bladder filling and emptying, bowel movements, and the movements of the patient, which will change the appearance on imaging. Transferring this variability in anatomy and these dynamics into models is a major challenge. So far, the greatest use of simulation has been in the teaching of normal anatomy and of standard surgical cases. The next frontier is implementing these technologies in the surgical planning and training of complex individual cases.

Key Points

- 3D models, VR, and 3D printing are useful for anatomy teaching and training of the female pelvic floor.
- The intrinsic variability of the anatomy of the female pelvic floor due to changes following childbirth, menopause, etc., makes it difficult to use 3D modeling for the surgical planning of individual cases.

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Chapter 14
Simulation in Penoscrotology and Urinary Catheterization

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14.1 Introduction

Diagnosis of penoscrotal conditions and surgery, as well as catheterization, are basic but frequently performed urological procedures in every urological practice around the world. "Practice by doing" is a great adage in these kinds of procedures. However, with optimal time-efficient training using simulation, one can master (parts of) the skills without putting patients at risk.

A simulation model is just part of the training. The main success factor of a practical simulation training session still relies on active and willing-to-learn trainees and willing-to-teach tutors. One of the most commonly seen pitfalls of training penoscrotal skills is that residents and urologists judge them as "simple," "basic," and "on-the-job" learning procedures. The consequences of these thoughts are that it is a common practice for young trainees to be "let loose" on this type of procedure on the patient rather quickly. Nevertheless, whether a procedure is simple or complex, every patient has the right to be treated by a doctor, student, or specialist nurse that is fully trained and has learned every step of the procedure that is possible to learn in simulation setting [1]. In this chapter, we describe the available models and evaluate their validity status.

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14.2 Physical Urological Examination

Physical examination is a skill that all medical students need to master. Especially in this phase of education, training models can be helpful in the first steps of mastering this skill. Once learnt, it is uncommon that residents are supervised in this skill, and even more uncommon is that urologists observe each other in this skill. However, as always in learning as well as maintaining skills, it is good to perform and practice procedures without the patient in a purely trainee-focused environment for the first time. In the context of lifelong learning, it is wise and interesting to reflect on individual approaches and manners among students and experts, even with basic skills, to find out that there are always new insights in the "hidden" urological practices.

For gynecological pelvis examination training, many simulators exist [2]. They vary from standard plastic anatomy models to task trainers and to complete electronic hybrid models. Multiple validation studies have been performed on these models. In 2013, Dilaveri et al. identified nine studies that evaluated the educational effects of pelvis simulators with different learning impacts [3]. In the last decade, even more advanced pelvis simulators have been developed.

For scrotal examination, there are fewer models available. The scientific literature on these training models or programs is scarce [4]. Sarmah et al. [5] created six models replicating key scrotal pathologies: epididymal cyst, epididymitis, hydrocele, inguinoscrotal hernia, testicular tumor, and varicocele. The estimated cost was low, at £8.5 ($11.55), and the preparation time was approximately 1 h. They used synthetic and animal materials to prepare models.

For training operative scrotal skills, one can use full animal material, for example, a bull's scrotum (Fig. 14.1).

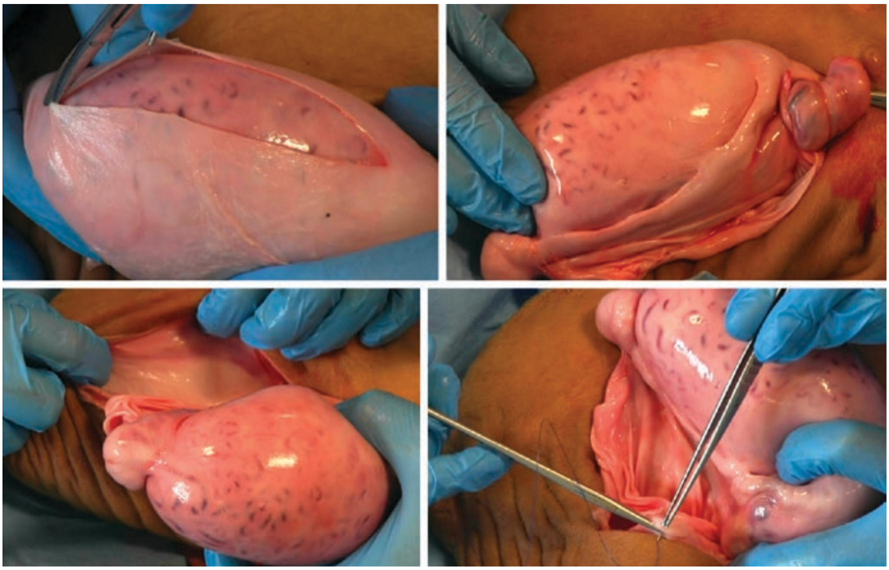

Fig. 14.1 The bull's scrotum to teach scrotal procedures

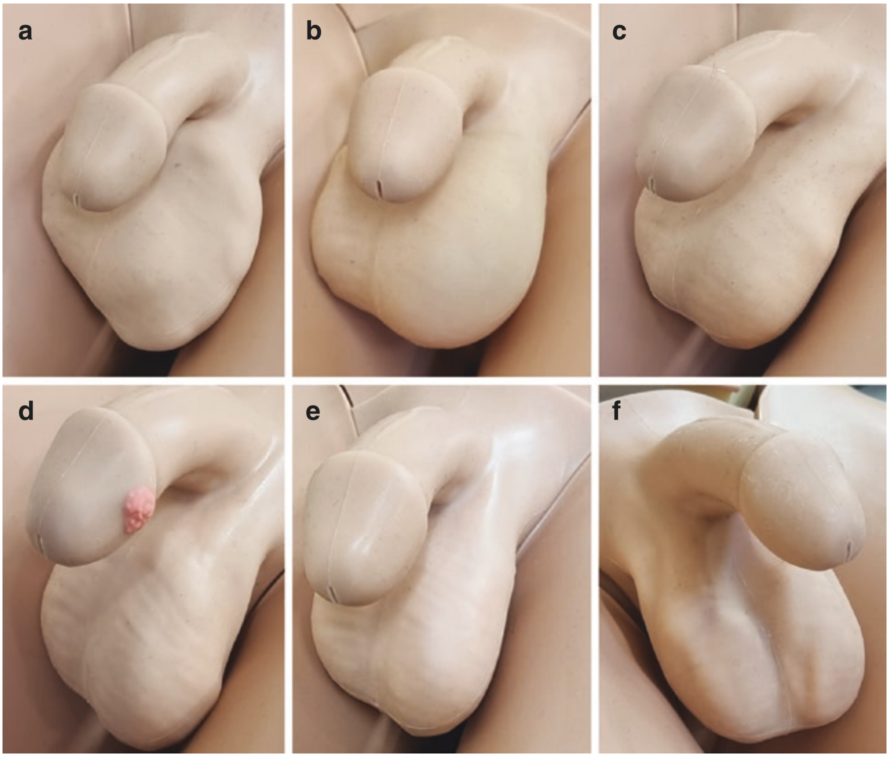

Fig. 14.2 Scrotal examination model with different pathologies: epididymorchitis (**a**), hydrocele (**b**), inguinal hernia (**c**), testicular tumor and penile ulcer (**d**), epididymal cyst (**e**) and varicocele (**f**) (Reproduced with permission from Limbs and Things Ltd.)

There are also commercially available plastic models to teach scrotal examination (Fig. 14.2). This model was evaluated by Kailavasan et al., and they concluded that the CMPT MK 2—Advanced models (Limbs and Things Ltd, Bristol, UK) have high "face validity" and may be a valuable tool for surgical education [6]. Also, training models are available to simulate hydrocele and epididymal cysts training (Fig. 14.3).

Several simulators for prostate palpation exist. The Male Rectal Examination Trainer (Limbs and Things Ltd, Bristol, UK) can be used with five different types of prostates. Other commercially available simulators are, for example, the Life/form® Prostate Examination Simulator (Nasco, Fort Atkinson, WI) and the G300 life-size prostate model set (Anatomical Chart Company, Skokie, IL, GPI Anatomicals).

3D printing is a novel technique that is being applied more and more in medical simulation. DeZeeuw et al. converted a pre-existing 3D human model and five different prostate models using Fusion360TM (Autodesk Inc., San Rafael, CA) into stereolithography files and altered them to produce negative molds [7]. The prostate molds were filled with silicone and polylactic acid filament "nodules." They evaluated content validity with five practicing urologists. The silicone models and task

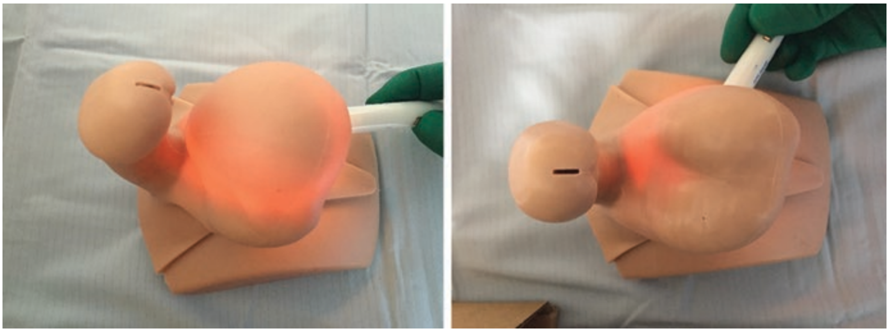

Fig. 14.3 Simulation of transillumination for Hydrocele and Epididymal cyst

trainers were found to be useful for simulation training when attempting digital rectal examination (DRE) techniques. The feedback from the participants was overall positive and provided recommendations for improvement, including stabilizing the prostate models in the task trainer, smoothening the transition between the rectum and the prostate, and adding an additional "normal" prostate model. Furthermore, Qui et al., Yanoshak et al., and Kowalik et al. also used 3D prostate printing techniques [8–10]. Kowalik et al. developed a prostate simulator from 21 ex vivo prostates within 20 min of surgical excision. All patients consented to have the material properties of their prostates evaluated [10]. Once developed, they evaluated the first part of construct validity with 12 urological surgeons. They found that it is not the absolute elasticity of the nodule, but rather the nodule's relationship with the background prostate elasticity that constitutes the critical tactile feedback. They indicated that before being incorporated into medical education, performance metrics require more rigorous testing [10].

Even though trainees can touch and feel the prostate gland through the rubber rectum, no visualization of finger movement or internal organs can be obtained because of its lack of transparency. Similarly, this model does not provide enough information for examiners to assess the techniques used by trainees to perform a DRE. Therefore, Muangpoon et al. evaluated the face and construct validity of their augmented reality digital rectal examination trainer system that was used on the MK 2 model [11]. They used the HoloLens as an augmented reality head-mounted display. To track and show the movement of the examining finger inside the benchtop model during the examination, they used a trakSTAR magnetic tracking system (Northern Digital Inc.) to obtain the position and orientation (pose) of the examining finger in real-time due to its ability to operate without line-of-sight (Fig. 14.4). Users found the movement of the finger realistic (mean 3.9, SD 1.2); moreover, they found the visualization of the finger and internal organs useful for teaching, learning, and assessment of digital rectal examinations (finger: mean 4.1, SD 1.1; organs: mean 4.6, SD 0.8), mainly targeting a novice group.

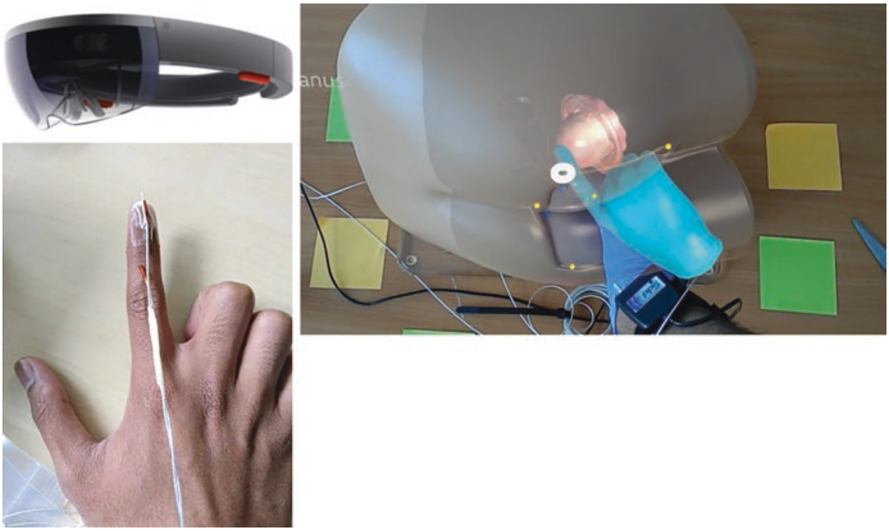

Fig. 14.4 Magnetic tracking for prostate examination training [11] (Reproduced with permission from Dr. Haghighi Osgouei and Prof. Bello)

14.3 Vasectomy and Vasovasostomy

14.3.1 Vasectomy

Vasectomy is a common elective procedure performed by urologists in the outpatient setting, and around the world, a variety of surgical techniques are used. Traditionally, there is the incision technique, using one or two scrotal incisions to deliver the vasa. However, nowadays, the percutaneous no-scalpel technique is also gaining popularity. No matter what technique is used, *the* procedural step that is most challenging remains the same: isolating the vas and pulling it upwards to the skin where you fix it and try not to let it go!

Simulation setting provides a good opportunity for training in this procedure. For this, a scrotal model that includes the funiculus with the vasa deferens is needed. Studies that focus on a simulation model specifically designed for training vasectomy are scarce. Coe et al. [12] have designed a low-cost model for training the percutaneous no-scalpel technique of vasectomy (Fig. 14.5). They aimed to develop a training tool that has a realistic feel and allows learners to gain confidence in delivering the vasa. This scrotal model is made up of three components: a length of bicycle inner tube, a piece of latex tubing, and a Penrose drain. The paper describes the different steps of the procedure, all of which can be practiced on the model. One of the procedural steps, namely "pulling the vas through the skin," is shown in Fig. 14.5B. No validation study of this training model has been conducted yet. Furthermore, no other literature is available regarding (validated) simulation models designed for vasectomy training.

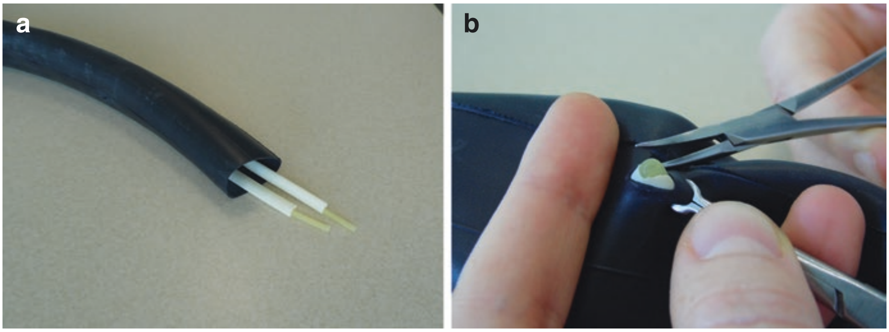

Fig. 14.5 The "vasa and fascia" inside the "scrotum" (**a**) and pulling the vas through the skin (**b**) [12] (Reproduced with permission from Dr. Curington)

Table 14.1 Overview of vasovasostomy models. No validation studies have been performed

Simulation model	Silicone medical grade tube Li et al	3D printed model Pinto et al	Rat model Shurey et al	Silicone tube vs rat model Grober et al
Study reference	[15]	[16]	[17]	[18]
Face validity	–	–	–	–
Content validity	–	–	–	–
Construct validity	–	–	–	–
Predictive validity	–	–	–	–

14.3.2 Vasovasostomy

Vasovasostomy (VV) is one of the few urologic procedures that requires microsurgical skills. These skills involve the use of an operating microscope or high power magnification and delicate surgical instruments. The importance of skills training before conducting VV in a clinical setting was emphasized by Nagler et al. [13] They performed a survey that assessed the patency rate of urologists who had participated in a microsurgery course versus urologists who had not. The group that performed microsurgical VV without practice had a patency rate of 53%, compared with an 89% patency rate for the urologists that practiced their microsurgical skills in a laboratory before employing them clinically.

In a recent review by Javid et al. [14], all available simulation models for training microsurgical skills (bench, cadaveric, live animal, and virtual reality) have been nicely summarized, including their validation status. In this review, no simulation models were outlined which focused on the VV procedure in specific. However, when looking closer in the literature, several simulation models specifically for VV have been described (Table 14.1).

Li et al. [15] designed a soft silicone medical grade tubing as a prototype of the vas deferens. The tube is held with a microspike approximator. The inner layer of the tube is used to simulate mucosal suturing and the outer layer of the tube simulates the placement of muscularis and adventitial layer sutures. No validation on this model was performed.

Pinto et al. [16] have designed a vasectomy reversal model using 3D printing (Fig. 14.6). The vas deferens ducts were made of translucid silicon tubes with a different internal and external diameter, allowing the simulation of all vas deferens layers. The holder for the artificial ducts was made from a small box using a 3D

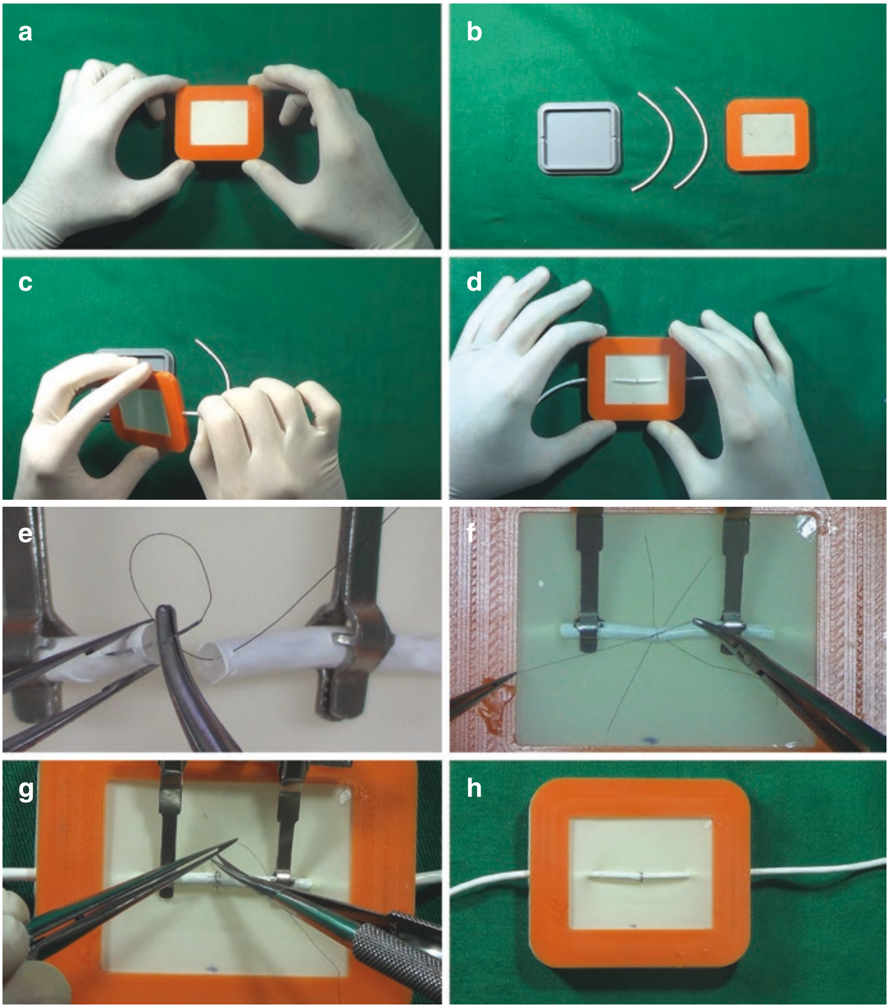

Fig. 14.6 Vasectomy reversal model via 3D printing [16]. (**a**) and (**b**): model components; (**c**) and (**d**): assembling of the components; (**e**): stitches applied through all duct layers; (**f**) and (**g**): microsurgical sutures; (**h**): proof of a patent anastomosis (Reproduced with permission from Dr. Pinto)

printer, MakerbotR. For validation of this model, five residents with no previous microsurgical experience undertook five training sessions of 1 hour on the model, with an interval of 1 week, in which they performed a VV. The authors found an improvement in time spent on microsurgical sutures and an increase in scores on an objective performance checklist. Face, content, and construct validity were not evaluated in this study. Moreover, it is not known whether improved performance on the simulation model is associated with an improvement in live surgery (predictive validity).

Besides these low-fidelity models, animal models for VV have also been described. Shurey et al. [17] emphasize that the rat models of vasovasostomy and epididymovasostomy are good substitutes for clinical operations due to their relatively large size in the rat and are used routinely in vasectomy reversal workshops for urologists in the UK. No further details are given.

Finally, Grober et al. [18] compared a rat model and a low-fidelity model consisting of a silicone tube and evaluated the impact of bench model fidelity on the acquisition of technical skills. Fifty residents participated in a 1-day microsurgical training course, randomized into 1 of 3 groups: (1) high-fidelity model training (live rat vas deferens) (2) low-fidelity model training (silicone tubing); or (3) didactic training alone. All participants were assessed on the high- and low-fidelity bench models, measuring procedural time, expert assessment of videotaped performance using checklists and global rating scales, anastomotic patency, and the presence of sperm on microscopy after 30 days, among others. They found that surgical skills training on low-fidelity bench models appears to be as effective as high-fidelity model training for the acquisition of technical skills among novice surgeons.

14.4 Circumcision

Circumcision is a common procedure in the adult and pediatric populations. The procedure is performed by urologists and general surgeons. The procedure is associated with complication rates of 0.5–7.6% due to the lack of optimal standardized training [19–21]. Most of the training in circumcision appears to be taught “on the job” during surgery on children and adult patients in the majority of countries [22]. A survey demonstrated low confidence in neonatal circumcision training, and therefore, a training program that incorporates appropriate hands-on training should be considered [21]. Training models for teaching pediatric and adult circumcision are available and gradually included in curricula [23, 24].

Saleh et al. created a training model to teach neonatal circumcision using two balloons, aluminum foil, and surgical tape [23]. A total of 47 physicians used the model, 42 agreed that the model replicated neonatal circumcision, and all 47 physicians were willing to consider incorporating the model into the training program.

Brill and Wallace developed a model to test the use of the Gomco clamp for circumcision [22]. They developed the model using a cocktail wiener and a surgical glove finger. The authors reported a significant improvement in knowledge, and 90% of the participants were competent in all 15 domains of a checklist.

Simulation of adult circumcision can be performed with well-established models and is a core skill tested in the UK National Selection for residency training in urology. A simple model to teach circumcision was created using a penile model (Pharmabotics Limited, Winchester, United Kingdom) and a simulated bowel (Limbs and Things, Bristol, United Kingdom). A total of 12 trainees performed circumcision, and satisfaction scores ranged from 7 to 10 (median 9) [25]. The authors also recommended their model for simulating penile ring block, paraphimosis reduction, and priapism aspiration. They have reported face and content validity for all these procedures. They reported the model cost around £22 ($30) and could be used by four trainees. The model from Limbs and Things, Bristol, UK (Fig. 14.7) includes a penis and scrotal model (light and dark color) with a disposable foreskin made of synthetic bowel (light and dark color). The costs £170 ($230) with a pack of five foreskins, but these can also be purchased individually (£8.00, $11.00). It has revealed a good face and content validity [26, 27]. The model also allows simulation of the penile ring block.

The British Association of Urological Surgeons (BAUS) Human Cadaver Training Programme has demonstrated face and content validity among 75 participants and 27 experts for the simulation of circumcision on fresh frozen cadavers [28].

Muhammad et al. developed an interesting mobile augmented reality circumcision training application (Circumcision Augmented Reality Simulation—CARS) and has tested through smartphones but it needs further studies to assess reliability [29].

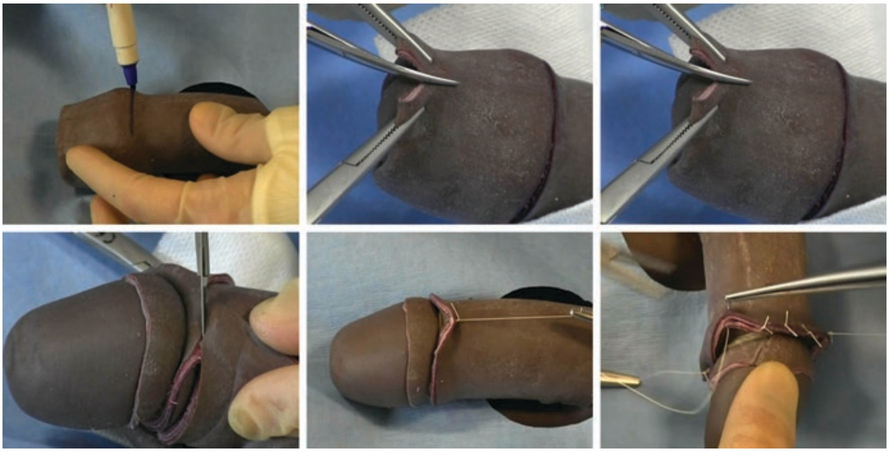

Fig. 14.7 Circumcision simulation (Reproduced with permission from Limbs and Things Ltd.)

14.5 Paraphimosis

Paraphimosis is a common urological emergency. Due to the nature of its presentation, it is not possible to electively regulate students' and residents' training in the skills needed to manage this condition. Hence, it is even more important to train for this presentation in a learner-focused setting. In the literature, no specific training model purely aimed at paraphimosis education has been described. However, of course, multiple circumcision training models can be used for this goal. Moreover, it is not only the hands-on skills one needs to train but also the scenario and materials. Several (national) training programs have already incorporated training on this procedure into their programs, for example, in the United Kingdom and the Netherlands.

14.6 Priapism

Priapism is a relatively uncommon urological emergency encountered by urology and emergency department residents. A needs assessment performed for emergency department residents training reported that 36% of residents felt underprepared in the management of priapism [30, 31]. Dai et al. developed an education and simulation program. The task trainer used in the program was rated easy to use (average score: 4.78 out of 5), and 77.8% of participants thought it was somewhat or very useful for training (average score: 4.00 out of 5).

A low-cost model was developed with a household sponge, 1-inch Kling gauze, endotracheal tube stylet, simulated bowel, and foam to simulate corporal aspiration. A total of 17 participants evaluated the model and rated it 4.64 on a 5-point scale (1 = not at all useful and 5 = extremely useful) [32].

Furthermore, an interesting model was suggested by Fritzges et al. They used Plaster of Paris molds with space for corpus cavernosi simulated by balloons [33]. Priapism was replicated by insufflating balloons with “blood” (water/corn starch/red food coloring mixture) pumped through a tube. The model cost was around £11 ($15) per model, and both balloons needed to be replaced for each trainee. The model appeared to be simple, but there was a lack of participant feedback.

Recently, a model developed using a catheterization model by Berridge et al. reported the best simulation trait of the priapism model [34]. Tactile feedback from needle insertion for aspiration was also felt to be realistic, with 72.6% reporting it as “good” or “very good” and 85.7% reporting the model to be realistic for needle insertion. The intra-class correlation among experts was 0.552. The majority of trainees (83.3%) reported a realistic simulation.

14.7 Peyronie's Disease

A 3D-printed model of a curved penis and graft to simulate plaque incision and graft surgery showed good face and content validity [35]. The model was created using a flexible filament of thermoplastic polyurethane with a 60-degree curvature and an accompanying urethra. A total of 20 urologists (12 experts and ten trainees) were enrolled to assess the model. The authors reported the mean usability score was 4.25 and the overall experience scores were 4.75 (expert) and 5.0 (trainee). The authors used a simple 3D printer to develop the model using the stereological file (.stl) and flexible filaments with a production cost of around £0.74 (1$) per unit.

14.8 Penile Fracture

A penile fracture simulation model has been reported in the literature. Kozan et al. used the penile circumcision model (Limbs and Things, Bristol, UK) and a double layer of simulated foreskin with a red jelly tablet to mimic the clot to create the penile fracture model [36]. The authors evaluated the model with 22 urology trainees and four experts and reported good face and content validity.

14.9 Transurethral Catheterization

Nowadays, there should not be nurses and/or doctors who have learnt to perform transurethral catheterization directly on a patient. This is due to the fact that training models for this procedure are one of the oldest and certainly one of the most used in the daily educational practices of health care workers. There are two main reasons why these models are used so frequently, in contrast to some other training procedures described in this book. First, it is a basic procedure that almost every nurse or doctor has to master and is incorporated into almost all training programs. Second, the manufacturing of such a model is easy. Many commercial designs exist that can be purchased for acceptable prices, and probably every hospital or medical educational institution has at least one available for trainees. Although it is in common use, scientific literature on transurethral catheterization models is scarce [37]. We found one paper that presented a 3D printed model for transurethral catheterization and evaluated face validity among novices [38].

14.10 Suprapubic Catheterization

Suprapubic catheterization (SPC) is a basic procedure for every resident to master. However, it is not free of risks and complications. Moreover, it is often placed in an acute crisis situation with sometimes less beneficial circumstances for residents to learn at ease. Therefore, it is highly preferable to first train on this procedure with simulation before “practicing” on the patient.

Of course, all steps of the procedure, including the preparation of the materials and the patient, communication with the team, etc., can be performed. One of the challenges, however, for simulating and scenario training of this procedure is to provide the educational program with a training model that comes close to the real-time situation of the feeling of the puncture. The feeling of “to push,” but do not push too deep or too firm, is one of the most difficult aspects of the procedure, and yet also one of the most difficult steps to train on a simulator.

In the literature, several SPC training models have been described [39] (Table 14.2). Shergill et al. constructed the UroEmerge model out of a 3 L bag of irrigation fluid, which was tied with tourniquets, placed in a plastic trainer and covered with an abdominal open and closure pad [40]. The researchers attempted to investigate construct validity among 36 candidates who were assessed on a visual analog scale 1–5. Their ability to perform SPC insertion was 3.14 before the course, and 4.48 immediately after the course. However, this decreased to 3.89, 3 months after the course.

Singal et al. aimed at optimal reproduction of the anatomy with bony landmarks [41]. Content validity was researched among six expert urologists and scored between 3.9 and 4.5 on several items on a 1–5 Likert scale (1 not at all realistic, 5 highly realistic). Face validity was reviewed among general surgeons who learned the SPC procedure during a specialized surgical skills course. The lowest score was the “life-like feel of the simulator” with a mean of 3.4, and the highest was “the ability to perform the procedure” with a mean of 4.1.

Table 14.2 Overview of SPC models and their validity

Simulation model	UroEmerge Shergill et al.	SPC trainer Singal et al.	SPC trainer Hossack et al.	US-SCIT Nonde et al.	Suprapubic paracentetic cystostomy model Gao et al.
Study reference	[40]	[41]	[42]	[43]	[44]
Face validity	–	+	+	+	–
Content validity	–	+	+	+	–
Construct validity	+	–	–	–	+
Predictive validity	–	–	–	–	–

Hossack et al. designed a low-cost model of disposables in which the only part that had to be replaced after every training procedure was a water balloon [42]. Experiences were evaluated by face validity in 25 trainees. Twenty-four (95%) felt that it very much represented a bladder and 21 (85%) felt much more confident in performing an SPC insertion.

Another low-cost "plastic-box" trainer was developed and assessed by Gao et al. [44]. A total of 40 students were enrolled in this study and were randomized to either an experimental or a control group. Six experienced urologists assessed the students. The experimental group was asked to read the literature related to this topic, watch an instructor's video of suprapubic catheter insertion, participate in preparing the model, and practice the procedure on the model. The control group also reviewed literature and watched the instructor's video, but did not receive hands-on training. This construct validity study showed a significantly higher final score in the experimental group than in the control group.

Some use animal materials, such as a porcine abdominal wall and small bowel [45]. Content validity was evaluated among ten urologists and experts who reported high satisfaction with their experience on the simulator as a training tool.

Learning to use ultrasound during the SPC procedure is also an interesting aspect. Nonde et al. validated the US-SCIT (ultrasound-guided suprapubic catheter insertion trainer) model [43]. They constructed this model of every item commonly found in the emergency department, which takes 8 min to construct. They investigated face/content validity among 50 participants, with mean scores of 7.8–9.1 on a 0 (no value) to 10 (greatest value) Likert scale.

14.11 Summary

Training of basic urological skills can be done without putting a patient at risk, in a learner-focused setting. Multiple training models are available and suitable, although no scientific studies exist that have performed research to assess the effectiveness of these models based on 3 or 4 levels of the Kirkpatrick model. Most training models for these purposes are low-cost non-animal models. For physical examination, low-fidelity and augmented reality simulation models exist. Most training equipment is low-fidelity models, which from an educational point of view is appropriate for training basic urological procedures. It is also acceptable from a cost-efficient point of view.

Key Points
For basic urological skills (penoscrotal and urinary catheterization procedures), training models are available and suitable, although no scientific studies exist that have performed research to assess the effectiveness of these models based on 3 or 4 levels of the Kirkpatrick model.

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Chapter 15
Simulation in Advanced Open Urology Procedures

Mamoun H. Elmamoun

15.1 Introduction

Open surgical training has traditionally been based on the apprenticeship model of "see one, do one, teach one" [1]. While this model was effective in educating and training surgeons in generations gone by, this is no longer the case. The opportunities available for trainees to spend time in an operating theater have become more restricted. Time constraints due to working time directives, larger cohorts of trainees, and shortened shift patterns have led to a reduction in exposure and a lack of continuity between trainers and trainees [2, 3]. It is acknowledged that the majority of surgical errors occur in the operating room during a surgeon's initial learning curve [4, 5]. The growing emphasis on patient safety, increasing litigation, and heightened patient expectations have meant competencies can no longer be solely gained on a live patient [6]. The result has been a shift away from the operating room and toward simulation-based models [7].

Urology has always been at the forefront of advancements in technology, techniques, and training methods. Owing to the closed cavity nature of robotic, laparoscopic, and endo-luminal procedures, these lent themselves particularly well to virtual reality and bench-top synthetic simulation training [8].

Simulation training in open surgery has remained a challenge. Advancements in minimally invasive techniques have meant that a large proportion of traditional open surgical procedures are no longer being performed open. The ease with which simulation models can be tailored to these minimally invasive techniques means that the learning curves for trainees can be safely and effectively monitored. Competencies can subsequently be assessed and validated in a structured method [9]. A role for open surgery, however, still remains. Minimally invasive techniques are yet to fully

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negate the need for open surgical skills in complex elective surgery and particularly in the emergency and trauma settings.

Exposure to advanced open surgery during a trainee's residency remains limited by available opportunities. Many trainees nearing completion of their residency remain apprehensive about their competency levels in these areas. A survey of UK trainees highlighted the limited exposure and confidence levels of senior trainees in open surgical skills [10]. Simulation has thus emerged as an invaluable tool in gaining these critical competencies required for completion of training. Simulation training has therefore been formally integrated into the latest surgical training curriculum in the UK. Hands-on training as part of the UK developed Urology Simulation Boot Camp (USBC) (discussed in more detail in Chap. 28) has become a mandatory requirement for all new urology trainees [9, 11].

Advanced open procedures present a significant challenge in their adaption into simulation models. This is reflected in the limited number of models available. While bench models have been shown to be effective in gaining core open urological competencies such as supra-pubic catheterization, circumcisions, and vasectomy, more complex or advanced procedures such as ileal conduit formation and ureteric re-implantation have continued to be mainly acquired through animal and cadaveric models [12].

15.2 Ileal Conduit

An ileal conduit remains the most frequently performed urinary diversion following radical cystectomy. It is still considered the "standard" given its reliability, cost-effectiveness, and clinical adequacy [13]. It involves isolating a 15–20 cm segment of ileum, restoring bowel continuity via a primary anastomosis, formation of a uretero-ileal anastomosis at the proximal end of the isolated segment, and construction of a stoma to the abdominal wall at the distal end.

The formation of an ileal conduit continues to be included in the Intercollegiate Surgical Curriculum Programme (ISCP) in urology. The minimum level of competency required for certification is for a trainee to be able to perform the procedure fluently with assistance. Trainees with a specialist interest are required to demonstrate the maximum level of competency by being able to construct the conduit with no assistance and demonstrate an ability to deal with any complications [11].

Numerous studies have demonstrated the validity of simulation models with regard to ileal conduit construction as part of robotically assisted radical cystectomy. This minimally invasive approach is gaining more popularity around the world and is fast becoming the standard approach to tackle muscle invasive bladder cancer. Virtual reality simulators have been deemed the best method for training future robotic surgeons [12].

There remains, however, a need to acquire the open skills necessary to deal with any complications and in situations where a minimally invasive approach is not feasible.

Simulation in this area has mainly involved synthetic, animal, and cadaveric models. The multiple steps involved in the construction of an ileal conduit have been taught and practiced via a range of simulation models.

15.2.1 Synthetic Models

A number of companies have sought to manufacture a double-layered synthetic bowel segment to enhance the trainee's experience in performing a small bowel end-to-end anastomosis. The Tactility Surgical Learning System was designed by a collaboration between The Chamberlain Group and the Department of Surgery at Baystate Medical Center, Massachusetts. It has demonstrated both face and content validity while achieving high-fidelity to human tissue when compared to porcine bowel [14].

Similarly, Sim*Bowel manufactured by Sim*Vivo has also shown favorable outcomes when compared to porcine bowel. These models provide a cost-effective and reusable option while retaining a similar level of fidelity to porcine tissue [15].

15.2.2 Animal Models

The use of animal models for education dates back to 500 BC. Simulation of operative skills on animals or animal parts has supplemented the training of surgeons for decades. Until a time comes when virtual simulations or synthetic materials can compete with the realism provided by animal models, their use is likely to continue. Porcine tissue remains one of the most widely used of these models in surgical training. A number of studies have shown it to be superior to synthetic models. The swine's urinary system bears a lot of similarities to that of a human. The comparable anatomical and functional aspects make its use in simulation models highly effective. Specifically, the accurate tissue consistency and similar dimensions to human tissue allow the learner to work in a more realistic environment [16].

A number of studies have demonstrated the face, content, and construct validity of live animal models in endourology and minimally invasive techniques [17]. Overall, however, the numbers still remain limited. The advantage of using these models is in the preservation of tissue texture and appearance. There is an obvious acknowledgement, however, that anatomy, while similar, is not identical to the human body. UK legislation only permits these procedures to be performed on anesthetized animals under the care of appropriately trained licensed individuals. The result is an increased demand on limited resources and time [18].

The USBC utilizes porcine models in the simulation of ileal conduit construction. This involves using small intestine that the trainees would initially divide and re-anastomose in a primary fashion (Fig. 15.1). This is followed by a second stage of performing a uretero-ileal anastomosis either using a Bricker or Wallace technique.

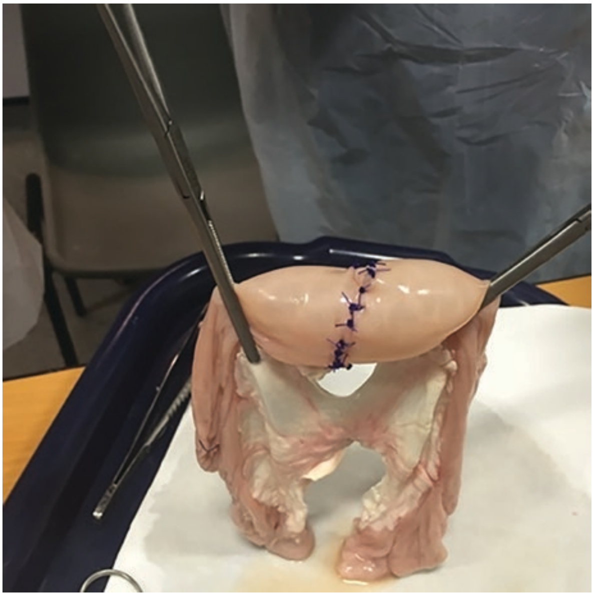

Fig. 15.1 Primary anastomosis of a porcine bowel segment (Courtesy Urology Simulation Boot Camp, Medical Education Dept, St James's University Hospital, Leeds, UK)

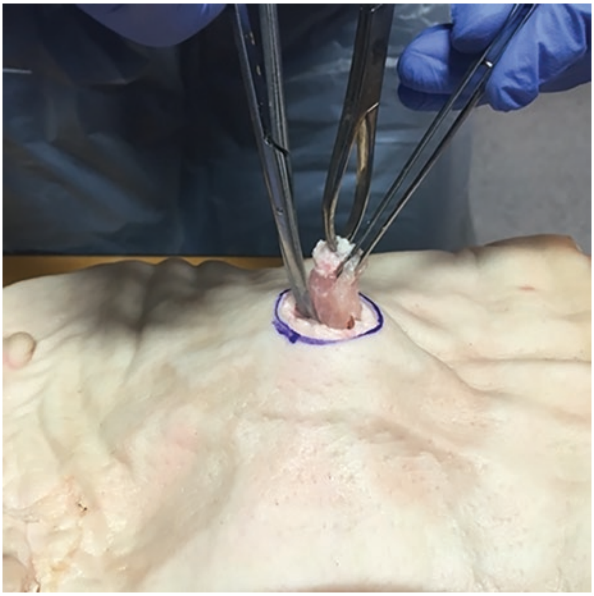

Fig. 15.2 Bowel segment being delivered through the abdominal wall (Courtesy Urology Simulation Boot Camp, Medical Education Dept, St James's University Hospital, Leeds, UK)

The final stage is the formation of the urostomy by delivering the distal bowel segment through a defect made through the porcine abdominal wall (Figs. 15.2 and 15.3). These steps are performed under one-to-one tuition with a consultant trainer. At each step, the trainee's generic skills in tissue handling, surgical instrument use, and operative techniques are continuously being formatively assessed. This model

Fig. 15.3 Urostomy anchored to the abdominal wall (Courtesy Urology Simulation Boot Camp, Medical Education Dept, St James's University Hospital, Leeds, UK)

allows the learner the opportunity to discuss the theory as well as the practical aspects with their assigned instructor. Feedback from both trainees and faculty has been overwhelmingly positive, leading to an increased knowledge level and operative competency [9, 19].

15.2.3 Cadaveric Models

The Human Tissue Acts of 2004 and 2006 have enabled surgeons to utilize cadavers for education and training [20]. The use of human cadavers provides a high-fidelity surgical simulation platform. This training method presents the best compromise between learning on live patients and learning on animal or synthetic models. Cadaveric training remains the gold standard in attaining competencies prior to operating on patients and is often delivered in master-classes. Cadavers provide the optimal method for attaining anatomical knowledge while accounting for human variability [21, 22]. The BAUS cadaveric simulation curriculum described by Ahmed et al. uses fresh frozen cadavers in the simulation of emergency and trauma urology. The trainees are exposed to hands-on high-fidelity training in a number of open procedures, including bladder perforation and ureteric re-implantation. Face and content validity have been demonstrated among participants [23].

The use of Fresh Frozen Cadavers (FFCs) for surgical simulation does have its limitations. This traditional method of embalming results in rigidity and stiffness of the tissues as well as discoloration. The increasing use of soft-fix embalming techniques such as the Thiel method has led to improved tissue texture and color while preserving shape and volume.

The Thiel method provides long-term preservation, with low toxicity and without the need for cooling. The fluid used is a mixture of glycol, water, oxidizing salts, bactericidal/antifungal agents, and a much smaller concentration of harmful components such as formaldehyde and 3-chloro-4-cresol. The use of a smaller proportion of these substances permits safer tissue handling compared to FFCs [24, 25]. Cabello et al. have demonstrated face validity in these high-fidelity Thiel cadavers in a simulation model for renal transplantation [26].

15.3 Ureteric Re-Implantation

The three main indications for ureteric re-implantation are ureteric strictures, malignancy, and iatrogenic injury. Despite the variety of indications, the procedure remains uncommon. This sporadic nature has naturally led to limited opportunities for urology trainees to gain adequate exposure and thus achieve the competency requirements for certification.

Minimally invasive techniques via robotic or laparoscopic-assisted approaches have been shown to have comparable functional outcomes to open techniques [27, 28]. Many authors have demonstrated that these technologically based modalities lend themselves more naturally to simulation models [29, 30]. The learner can hone their skills and overcome the learning curve in a safe, timely, and cost-effective manner. This, however, is largely limited to the elective setting. The need to perform a re-implant tends to occur most frequently in the emergency or trauma setting. There remains a significant void in training opportunities in open ureteric re-implantation whether associated with an intra-operatively or post-operatively recognized iatrogenic injury. A number of studies have highlighted the need for a standardized simulation setting to address the deficit recognized by senior trainees in their ability to competently undertake a ureteric re-implantation [11].

The British Association of Urological Surgeons (BAUS) Education Committee recognized the need to develop a high-fidelity simulation course to address the training deficits and standardize practice across the UK. This was achieved by firstly establishing the current level of exposure of UK trainees to uncommon urological emergencies and secondly, to construct a cadaveric course and assess its feasibility, quality, and results [31]. The mandatory UK USBC takes this a step further in ensuring all new urology trainees are exposed early to these procedures in the form of simulation. Both face and content validity have subsequently been demonstrated [23].

In recognition that the management of emergency cases is an integral part of a UK urologist's practice, the General Medical Council has made it a requirement for trainees to demonstrate competency in dealing independently with a range of emergency procedures, including ureteric injuries, in order to attain certification for independent practice.

Developments in simulation training for ureteric re-implantation have largely taken place in the minimally invasive setting. Comparable functional outcomes from laparoscopic and robotically assisted procedures have meant a global decline in the frequency of open re-implants being performed. This, coupled with the infrequent nature of the presentation, has led to a reduction in the levels of competency and proficiency among trainees. Numerous models have been suggested and implemented to hone these minimally invasive skills. A number of which have shown face and content validity [29, 30]. The open approach, however, has fared less well from a simulation point of view. Due to a lack of bench and virtual reality models, open re-implantation has continued to rely on animal and cadaveric platforms.

15.3.1 Animal and Cadaveric Models

Porcine tissue has remained the most widely used form of simulation material. This is due to the close anatomical and functional resemblance to that of humans. Reconstruction simulation models using pig bladders and ureters have been used to teach end-to-end ureteric anastomosis, Transuretero-ureterostomy, and ureteric re-implantation, including psoas hitch and Boari flap.

The USBC utilizes porcine bladders and ureters to simulate a ureteric injury at different levels. The learner is then supervised by a consultant mentor in undertaking an open repair on a 1:1 basis (Figs. 15.4, 15.5, and 15.6). This facilitates

Fig. 15.4 Demonstration of the ureteric injury and planned uretero-vesical repair (Courtesy Urology Simulation Boot Camp, Medical Education Dept, St James's University Hospital, Leeds, UK)

Fig. 15.5 Preparations for a psoas hitch and intra-vesical tunneling of ureter (Courtesy Urology Simulation Boot Camp, Medical Education Dept, St James's University Hospital, Leeds, UK)

Fig. 15.6 Completed ureteric re-implantation with psoas hitch (Courtesy Urology Simulation Boot Camp, Medical Education Dept, St James's University Hospital, Leeds, UK)

discussions regarding clinical management decisions while observing the trainee's operative skills. The result is a high-fidelity simulation model that allows trainees to develop technical and operative skills while attaining the required functional and anatomical knowledge. The feedback from trainees reflects an increase in confidence levels if faced with a ureteric injury in the future [9, 19].

The BAUS Fresh Cadaveric Urology Training Programme provides an opportunity for training in emergency urological procedures, including open cystostomy with supra-pubic catheter insertion, prostatic cavity packing, ureteric re-implantation, loin approach, and emergency nephrectomy. Face and content validity were established among 75 residents and 27 experts. A statistically significant increase in confidence scores was seen in ureteric re-implantation and in primary ureteric anastomosis. All delegates would recommend the course to their peers and felt the course should be mandatory [23, 31].

An analysis of Thiel cadavers in surgical training concluded that the use of these cadavers in simulation ureteric re-implants was more favorable than FFCs. Thiel embalming has a number of advantages over traditional embalming techniques. These include reusability, slower deterioration, reduced infection transmission, slower deterioration, and lower storage demands and costs. Most importantly, however, the tissue quality preservation allows for a higher fidelity medium compared to FFCs. A cross surgical specialty evaluation carried out by Yiasemidou et al. has shown the pan-surgical suitability of Thiel cadavers in surgical training. Those rated most highly were anatomical accuracy and fidelity of tissue properties. The Thiel cadavers presented fewer issues with unpleasant odor, ethical constraints, and cost [32].

15.4 Open Kidney Procedures

Opportunities to experience open renal procedures have gradually reduced in the western world due to the introduction of minimally invasive procedures for upper urinary tract pathologies. Various studies have reported limitations within the urology programs and a study has also identified suboptimal exposure of residents to urotrauma. Unfortunately, due to complex anatomy and scenarios, it is difficult to achieve a high degree of fidelity with synthetic models to simulate advanced renal procedures [33–35].

15.4.1 Synthetic Model

Synthetic models for complex surgical skills are uncommon. Interestingly, Melkonian et al. developed a low-cost bench-top simulation model for renal transplantation. A kidney-shaped stress ball was reformed by taping 1.27 × 4, 0.64 × 4, and 0.64 × 15 cm (diameter × length) to mimic a left kidney transplant allograft and penrose drains were attached anteriorly, posteriorly, and inferiorly to reproduce the renal vein, renal artery, and ureter, respectively. The positioning of the Penrose drains can easily be modified to replicate a right allograft instead. A 10 × 10 cm piece of gauze was wrapped around the simulated allograft with two forceps to create a "jacket" for easy handling during vascular anastomosis. An opening was created in the gauze at the renal hilum area to leave the renal vein, renal artery, and ureter exposed (Fig. 15.7). The model was evaluated by 18 residents to learn suturing, operative steps, and assisting. They reported good fidelity and educational utility of the low-cost model ($134.30 with and $20.20 without sutures or surgical instruments) [36].

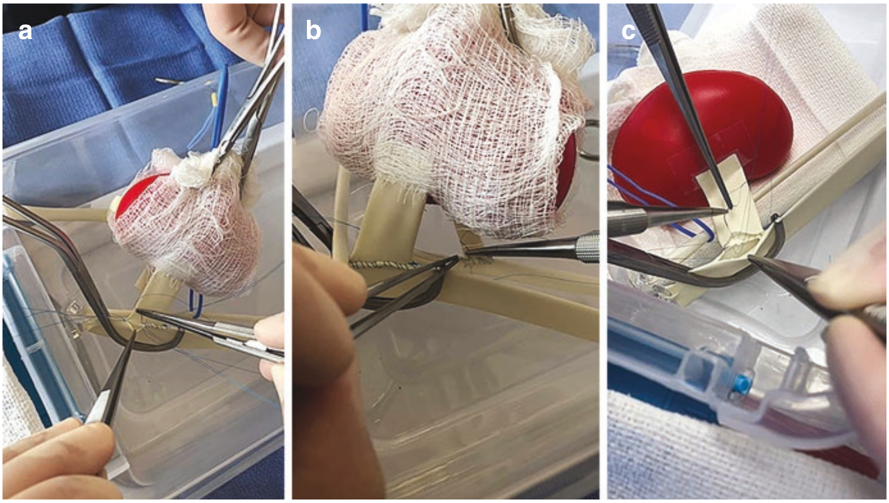

Fig. 15.7 Two residents work together on the bench-top kidney transplant surgery simulator. The images show residents performing the (**a**) venous and (**b**) arterial vascular anastomoses operative steps of a real-life kidney transplant. (**c**) An alternative technique to the venous anastomosis is demonstrated in which the back wall is performed from inside the lumen [36] (Reproduced with permission)

15.4.2 Animal Model

Porcine kidneys have been used successfully to simulate some steps of the partial nephrectomy operation, especially renorrhaphy. The main advantage is the relations of higher-fidelity tissue manipulation. The porcine ex vivo model has been used; however, face and content validity were not assessed (Fig. 15.8). In addition, the option to perfuse an isolated kidney allows assessment of hemostasis after renorrhaphy. The model has been validated for laparoscopic and robotic training [37].

The gold-standard surgical technique to manage ureteropelvic junction obstruction is the dismembered pyeloplasty. An open pyeloplasty model using chicken skin established effectiveness in improving knot tying and suturing ability among medical students ($p < 0.05$; first attempt 17.00 ± 4.44 min; mean ± 95% CI, third attempt 11.33 ± 2.40 min) using the open model. This model is low-priced and sufficiently replicates living tissue; however, the preparation time to produce the model was high [38].

15.4.3 Cadaveric Model

Cadaveric simulation has become an important component of simulation-based skills training. It has been accepted that it has the highest face validity of all simulation modalities [39]. Ahmed et al. evaluated the national cadaveric simulation program in urology in the UK and reported a good face and content validity for emergency trauma nephrectomy [23]. Bullock et al. also reported improvement in self-confidence in emergency nephrectomy after a 2-day emergency urology simulation course [31].

Coloma et al. evaluated Thiel-embalmed cadavers for renal transplant simulation. They used 39 cadavers and obtained 75 grafts. Two renal transplant procedures were performed on each cadaver. The authors concluded that the Thiel cadaveric model provides a highly representative simulation of the renal transplant operative step [40].

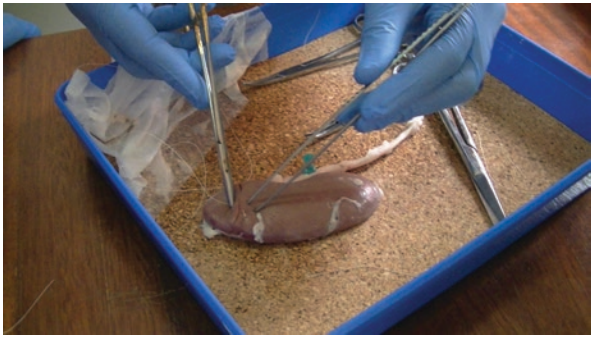

Fig. 15.8 Renorrhaphy on a porcine kidney

15.5 Future Developments

15.5.1 Artificially Perfused Cadavers

A further advancement in cadaveric simulation is likely to be the introduction of bleeding and hemostasis. Artificially perfused cadavers would combine the anatomical accuracy of human cadavers and the need for hemostatic control encountered in live animal models. The SIM Life, developed in France is an example of these perfused models which combines plastic, electronic, and biological materials to deliver a cadaver with a beating circulation and artificial respiration. Organ procurement was undertaken by ten surgeons to harvest the heart, lung, liver, pancreas, and kidney. The overall realism and correlation to normal anatomy were highly rated. Future application of such cadavers across all surgical specialties, including urology, should enhance the realism during cadaveric simulation [41].

15.5.2 3D Printing

Three-dimensional (3D) printing is likely to play a significant role in simulation training. The technology currently remains costly. It is, however, gaining momentum in delivering 3D models in a layer-by-layer technique. Its applications in urology have already been established and widely reported (more details in Chap. 26). A review by Smith et al. identified a number of urological procedures where 3D printing has been demonstrated to be applicable. These include percutaneous nephrolithotomy, partial nephrectomy, urethrovesical anastomosis, transurethral resection of the bladder tumor, and laparoscopic pyeloplasty [42].

Simulation for percutaneous nephrolithotomy using a 3D model was developed by Ghazi et al. The authors demonstrated both face and content validity among urology and interventional radiology trainees as well as experts [43]. Shee et al. created a similar model for vesico-urethral anastomosis during radical prostatectomy, while Van Renterghem delivered a 3D pelvic cadaveric model. Content and face validity were highly rated in both models [44, 45]. Currently, however, the level of evidence for the use of 3D printing remains low. Potentially, 3D printing can play a role in advancing methods of simulation-based training.

Claflin and Waits designed a low-cost, reusable, interactive 3D-printed model to simulate vascular anastomoses in kidney transplantation. The authors' aim was to improve basic open surgical skills and to generate interest in transplant surgery among surgical residents. The recipient abdomen was developed using a de-identified high-resolution abdominal and pelvic computed tomography (CT) scan of an individual with typical anatomy. This was imported into 3D Slicer open-source software (Slicer v4.10, www.slicer.org). The right lower quadrant of the abdomen was isolated, and separation of the right external iliac artery and vein and iliopsoas muscle on each slice of the scan was performed with a hand-contouring tool. The authors modified the stereolithography (STL) file with Materialise Magics STL editing software v20.03 (Materialise, Leuven, Belgium) and used Autodesk Fusion 360 v2.0.5966 (Autodesk, San Rafael, California) to design fasteners to secure Penrose drains to simulate the external iliac vessels. A Dimension Elite 3D Printer (Stratasys, Eden Prairie, Minnesota) was used to print the model with acrylonitrile butadiene styrene plastic. They also devised the kidney model in a similar way.

The authors recruited 12 surgical residents to assess the realism of the depth of vessels, anatomy of model realism, realistic depiction of anastomoses, ease of use, effectiveness as a teaching tool, and usefulness for surgical trainees. Almost 92% of residents preferred to have the model at home for training and all found the model to be effective for teaching. The authors reported at total cost of $178 (setup fee $20, model material cost of $137, support material $21), plus the cost of instruments and consumables [46].

15.5.3 Augmented Reality

Augmented reality (AR) has been used to aid surgeons during procedures for over a decade (see Chap. 25 for more information). In urology, AR has mainly been used in the field of robotically assisted prostatectomy. New systems, albeit at a research level have explored the challenging field of designing an augmented reality model to aid in open surgery. These can be employed at both patient and training levels. A review by Fida et al. highlights a number of papers which demonstrate AR to be a versatile and reliable tool during surgery. Applications that have shown promise include use in urogenital, pancreatic, and hepatobiliary surgeries [47]. The use in urogenital surgery was reported by KleinJan and van Oosterom in sentinel node biopsy in the penile cancer setting [48, 49]. Borgman et al. demonstrated the feasibility and safety of AR in a variety of urological procedures ranging from a simple vasectomy to a complex cystectomy using an AR head-mounted display [50].

Virtual interactive presence and augmented reality (VIPAR) aims to connect experienced surgeons with junior colleagues or trainees, allowing them to share their skills and expertise remotely during complex surgical procedures. This will narrow the gap in exposure and competency levels across all surgical specialties but may be particularly valuable in open surgical skills, which have been shown to be more difficult to acquire during training [51].

Patient-specific virtual reality (VR) incorporates up-to-date patient imaging in the form of computed tomography or magnetic resonance imaging into a VR program to allow a trainee the ability to tackle complex scenarios that otherwise would be beyond their level of competency [52]. A feasibility study successfully developed a virtual reality surgical simulation for open radical total abdominal hysterectomy. The aim of the study was to develop a low-cost system, using commercially available technology to construct a VR surgical oncology simulator. The modules were designed by experts in gynecologic oncology, learning sciences, human behaviors, and VR. The application would then be used to help train surgeons, augment safer surgery, and ensure higher standards. Future applications may play a vital role in disseminating the surgical expertise to a global audience including the developing world [53].

15.6 Summary

The acquisition of open surgical techniques and, in particularly, the complex skills required to deal with advanced procedures remains a critical issue for trainees. Ever changing times have led to reduced exposure levels within operating theaters, while at the same time, the emphasis on patient safety has minimized the reliance on traditional apprenticeship models. Simulation-based training has been recognized as a vital tool in supplementing and enhancing the capabilities and competencies of training surgeons. The incorporation of simulation into the surgical curriculum should provide trainees with a platform to hone their operative skills, overcome learning curves safely, and develop their technical and non-technical skills in a timely manner. As technology continues to heavily influence and shape surgical practice, there remains a crucial need for continued advancements to enhance open surgical techniques and training for future surgeons.

Key Points

- Exposure to complex open urological procedures remains limited.
- Construction of valid simulation models adapted to advanced open procedures is challenging.
- Cadaveric courses remain the gold standard for acquiring complex open surgical skills.
- Simulation-based training has and should continue to be integrated into the surgical curriculum.
- Future advancements may lie in the fields of 3D printing and virtual/augmented reality.

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Chapter 16
Low-cost Simulation in Urology

Dhananjaya Sharma, Vikesh Agrawal, and Chandra Shekhar Biyani

16.1 Introduction

Simulation as a means of learning or rehearsing surgery has a rich history, which is as old as surgery itself. Sushruta, an ancient Indian physician—2600 years ago, widely believed to be the "Father of Surgery," is credited with the use of fruits, vegetables, pieces of cloth/ skin/ hides, and cadaver-based experimental modules for teaching surgical skills [1–3]. These were the forerunners of modern low-cost simulation in which surgical residents practice tying knots, suturing on clothes, and train on animal organs.

Surgical skills, like any other motor skills, can only be acquired by repetitive practice, *i.e.* simulation; which consists of cognition, integration, automation, and finally, mental cognitive rehearsal of the proposed surgery [4, 5]. Simulation provides a much needed bridge between theoretical learning and real-life operating experience for a trainee and has become the foundation of modern surgical training. A recent bibliometric analysis of surgical education's 100 most cited articles found that the majority of publications were on surgical skill acquisition by simulation and its assessment and highlighted its importance [6].

Traditionally, simulations for surgical training were practiced in an autodidactic manner in rudimentary wet labs using animal parts procured from local butcher's shops or on cadavers. The advent of minimally invasive surgery demanded an upgrading of the science of simulations for learning new surgical skills, which had

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a significant learning curve due to impaired depth perception as visualization is on a two-dimensional screen, impaired tactile feedback, 2-handed choreography for dissection, non-dominant hand dexterity, accurate instrument targeting, intracorporeal suturing, different hand–eye coordination, familiarity with the fulcrum effect and, last but not least, working in a less ergonomically friendly position leading to earlier fatigability [7, 8]. Training opportunities in modern surgical skills centers were and are limited due to cost and availability [9–12]. This prompted the surgeons to unleash their ingenuity and led to the development of low-cost, easily available, and sustainable alternatives for simulation of surgical training. This was and remains very important in low- and middle-income countries.

16.2 Humble Beginning of Low-cost Simulation Systems

This revolution had humble beginnings in the form of "laparoscopy box trainers" which are made from the self-assembly of locally available/off-the-shelf/bought from online shopping portals components and even using used/discarded/expired disposable instruments (Table 16.1) [8, 13–16].

16.3 Advantages and Qualities of Low-cost Simulation Systems

Low-cost trainers are designed basically for novice surgeons to practice generic skills required for urological surgery. A low-cost simulation system has most of the advantages of a high-fidelity system: it allows repetitive practice of skills; can be used many times by multiple users; it permits the trainee to become familiar with anatomy (to scale, tissue texture, and accurate replication of anatomy), equipment, and techniques of surgery being practiced, so the learning curve associated with real

Table 16.1 Anatomy of low-cost box trainers for minimally invasive surgery

Component of simulator	Low-cost substitute
Abdominal cavity and wall	Plastic/cardboard storage box/metallic basket, two acrylic plates with hinge joints, plastic document holder case (Fig. 16.1)
Port site	Hole in the abdominal wall material (by cutting, drilling, or piercing)
Light source	External lighting (in case of transparent box), desk lamp, light-emitting diodes, fluorescent lights, inbuilt webcam, fiber optics
Visualization	Webcam, video camera, digital cameras, tablet/smartphone camera, and small camera mounted on a plastic pipe.
Camera monitor	Laptop/ desktop computer, TV/ video monitor, tablet, or smartphone.

From Sharma D, et al. [14]

Fig. 16.1 Abdominal wall model to simulate the Hasson open access technique [13]

patients can be avoided as much as possible; allows learning in a low-pressure atmosphere, without undesired interference while training in dedicated teaching time rather than patient care time; it allows a range of difficulties so training can be tailored to individuals; it is easily modifiable for various procedures and allows multiple learning strategies with defined outcomes; objective assessment of trainees is possible; it allows for judging the technical skills among participants of varying expertise; it permits refresher training of skills for senior trainees; it provides a facility for feedback and can be integrated within a training curriculum; and it can be reliably reproducible and valid [14, 15, 17–20]. In addition, it is low cost, low maintenance; with easy and cheap construction so as to be accessible to trainees worldwide. Trainees can better understand the "science" of skills to be acquired if they are involved in designing such systems [21].

16.4 Low-cost Technical Skills Simulation Systems in Urology

A recent review has given an encyclopedic and scholarly evidence-based account of the current status of simulation training in urology; including models for open urology, biological and non-biological models for endo-urology, and various laparoscopic and robotic models [22]. Similarly, all low-cost simulation models in urology have been appraised by a recent comprehensive review which defined low-cost models as those costing 150 US$ or less [23]. Many low-cost simulation models in urology have been summarized in Table 16.2.

As Table 16.2 shows, several low-cost models are now available for adult circumcision (Fig. 16.2), dorsal slit, and paraphimosis reduction at a cost of <$10 (Chap. 14); some of which show good face and content validity. Before the advent of low-cost models for supra-pubic catheter (SPC) insertion, it was not easy to acquire this skill, prompting junior doctors to frequently persist with urethral

Table 16.2 Low-cost simulators in Urology (Modified from Sharma et al. [14] and Pelly et al. [23])

Surgical procedure	Simulated with the use of	Cost in US$	Ease of construction	Validity Construct/ Face/ Content	Educational impact[a]
Adult circumcision, dorsal slit, and paraphimosis reduction					
Abdulmajed et al. [24]	Model penis which is then covered with simulated bowel in which the 2 layers of the prepuce are simulated by folding the simulated bowel on itself; and corona is simulated by applying a rubber band	$5.5	Yes		
Campain et al. [25]		$8	Yes	Face + Content	
Kigozi et al. [26]	Wooden penile model; different colored cloth to simulate two layers of prepuce	$5–10	Yes		
Acute ischemic priapism					
Dai et al. [27]	Hot dogs and candy to simulate priapism	$1.25	Yes		Yes
Eyre et al. [28]	Household sponge, foam, simulated bowel, glue, medical tape, simulated blood	$130			Yes
Supra-pubic catheter insertion					
Nonde et al. [29]	Open wooden/ plastic box/ lunch box (simulating abdomen) covered with urethane foam/ abdominal open and closure pad/ covered with gelatin/ surgical tape (simulating abdominal skin and rectus sheath) and a party balloon, glove filled with water/ 3-L bag of irrigation fluid tied with two tourniquets to simulate a full bladder	<2 $	Yes	Face	
Shergill et al. [30]		NA	Yes		Yes
Gao et al. [31]		<$2	Yes	Face	Yes
Singal et al. [32]		$31	Yes	Face	Yes
Hossack et al. [33]		$10			
Olapade-Olaopa et al. [34]		NA		Face	Yes
Palvolgyi et al. [35]		$60			
Suprapubic catheter exchange					
Bratt et al. [36]	Porcine abdominal wall; a segment of small bowel stitched around a size 16F Foley catheter to form a tract which was anastomosed to a porcine urinary bladder	<$25			
Open prostatectomy and radical prostatectomy					
Rowley et al. [37]	Orange as prostate glued to a milk jug glued to a flat surface	<$10	Yes	Face and content	Yes

Table 16.2 (continued)

Surgical procedure	Simulated with the use of	Cost in US$	Ease of construction	Validity Construct/ Face/ Content	Educational impact[a]
Lawrentschuk et al. [38]	The SP model used a ripe clementine fixed on foam or cardboard, the skin represented compressed normal prostate, the pulp represented benign tissue, the pith mimicked fibrous adhesions, and a party balloon inserted into the center of the fruit as the urethra.				
	The Radical Prostatectomy model used a Foley catheter with ballistics gelatin in the balloon and mesh fabric (as neurovascular bundles) and balloons (as prostatic fascial layers) on either side for the practice of inter- and intrafascial techniques.				
Diagnostic and therapeutic cystoscopy					
Schout et al. [39]	A white plastic box in which a prepared pig bladder is placed				
Teoh et al. [40]	Porcine bladder training model for transurethral resection of bladder tumor			Construct, Face, and Content	Yes
Grimsby et al. [41]	Porcine bladder with urethra fixed on an acrylic platform			Face	Yes
Persoon et al. [42]	Glass globe model of urinary bladder	$8	Yes		Yes
Bowling et al. [43]	A round balloon to simulate the bladder marked with markers for the demonstration of vessels and different pathologies.	$10	Yes		Yes
Bowling et al. [44]	Fresh frozen cadavers	NA	Yes	Construct	Yes
Hammond et al. [45]	Pumpkins and green peppers to simulate urinary bladder	$10	Yes		
TUR prostate					
Hammond et al. [45]	Porcine liver submerged in irrigant within a cored out pumpkin	<$15			
Biyani [46]	Potato	$1	Yes		
Bach et al. [47]	A Tupperware box, 7 cm of a 30F garden hose and different meat types as prostatic tissue	$40	Yes	Construct and Content	Yes

(continued)

Table 16.2 (continued)

Surgical procedure	Simulated with the use of	Cost in US$	Ease of construction	Validity Construct/ Face/ Content	Educational impact[a]
Biswas et al. [48]	Potato as Prostate	<$1		Construct, Face, and Content	
Ureteroscopy					
Hammond et al. [45]	Porcine kidneys with intact ureters with pebbles inserted to simulate stones				
Matsumoto et al. [49]	Penrose drain, inverted cup, molded latex in portable plastic case and 2 embedded straws approximately 8 mm. In diameter as substitutes for urethra, bladder dome, bladder base, and bilateral ureters, respectively.	$15	Yes		
Percutaneous renal surgery					
Hammond et al. [45]	Porcine kidneys with intact ureters placed inside an eviscerated chicken carcass to simulate posterior abdomen wall	$12	Yes	Face	
Hacker et al. [50]	Ex vivo perfused porcine kidney surrounded by ultrasound gel placed in the eviscerated chicken carcass for ultrasound- and fluoroscopy-guided access.	$10	Yes		
Qiu et al. [51]	Porcine kidneys with intact ureters and chest wall to simulate the feel of 12th rib				
Vijayakumar et al. [52]	Porcine kidneys with intact ureters placed inside an eviscerated chicken carcass	$10	Yes		
Ewald et al. [53]	Ballistic gelatin mixed with radiographic contrast was poured into surgical gloves to create a radio-dense renal collecting system. The collecting system model was then embedded in a pure ballistic gelatin block resting upon a clear acrylic glass base. Finally, the model was covered by a visually opaque polyurethane foam cover with chalk sticks positioned to simulate ribs.	$10	Yes	Construct and Content	

Table 16.2 (continued)

Surgical procedure	Simulated with the use of	Cost in US$	Ease of construction	Validity Construct/ Face/ Content	Educational impact[a]
Sinha et al. [54]	A bottle gourd was used to mimic the posterior abdominal wall. Cotton pledgets dipped in intravenous contrast were fitted into 4 mm holes made at staggered levels in the bottle gourd which was strapped onto the operating table with the cotton pledgets facing away from the surgeon.	$60	Yes	Face	
Lezrek [55]	Glove fingers filled with saline and contrast media to simulate calyceal system covered by foam to simulate abdominal wall	$5	Yes	Construct	
Open/laparoscopic dismembered pyeloplasty					
Ooi et al. [56]	Reconfiguring and suturing chicken skin dissected off its muscle to create a model of the ureteropelvic junction		Yes	Construct	Yes
Ramchandran et al. [57]	Crop and esophagus of a chicken				
Jiang et al. [58]	Crop and esophagus of a chicken		Yes		Yes
Rod et al. [59]	A4 Kraft envelopes, catheter tip syringe filled with 30 mL of air, tape, modeling and party balloons		Yes	Construct	Yes
Teber et al. [60]	Porcine bladder		Yes	Construct, Face, and Content	Yes
Sekhon [61]	Rubber balloon and tube model (Fig. 16.4)				Yes
Thompson [62]	Foam sponge, glove, latex tubing	<$2	Yes		
Laparoscopic renal surgery training/difficult nephron sparing surgeries					
Smektala [63]	Silicone replicas of kidneys using 3-D printer	$22		Face	
Robotic pyeloplasty					
Timberlake et al. [64]	Silicone cast over 3-D molds	$1.32/ model		Construct and Content	

(continued)

Table 16.2 (continued)

Surgical procedure	Simulated with the use of	Cost in US$	Ease of construction	Validity Construct/ Face/ Content	Educational impact[a]
Bendre et al. [65]	Silicone cast over 3-D molds			Face and Content	Yes
Urethro-vesical anastomosis in radical prostatectomy					
Yang et al. [66]	Chicken skin model				Yes
Laguna et al. [67]	Chicken esophago-stomach junction model		Yes	Construct	
Jiang et al. [68]	Chicken posterior trunks and porcine colon			Face	
Sabbagh et al. [69]	Latex model with Foley catheter			Construct	
Johnson et al. [70]	Silicone cast over 3-D molds			Construct, Face, and Content	Yes
Shee et al. [71]	Silicone cast over 3-D molds		Yes	Face and Content	
Laparoscopic ureteric re-implantation					
Singh et al. [72]	Chicken crop as urinary bladder and trachea as ureter placed in a box trainer		Yes	Construct, Face, and Content	
Thompson [62]	Foam sponge, glove, latex tubing, IV set				

[a]Educational impact = Use of model showed improvement in trainees' performance, TUR = Transurethral Resection

catheterization, with an increased risk of urethral injury [33]. Low-cost SPC models are few (<10 in number), with material costs ranging from <$2 to $60 per model. The lack of their validity and incorporation into structured curricula remain their main limitations [73]. Simple, low-cost models for training in TUR Prostate using potatoes (Fig. 16.3) or apple have been shown to be realistic with proven face, content, and construct validity [48, 46]. Similarly, low-cost diagnostic and therapeutic cystoscopy models have used porcine bladder, glass globe, round balloon, fresh frozen cadavers, and pumpkins and green peppers to simulate urinary bladder; many of which have shown improvement in trainees' performance (Table 16.2).

Many low-cost simulations use porcine, chicken, and beef models; as these have inherent natural tissue properties important for the acquisition of higher surgical skills such as dissection, suturing, and use of energy sources with the same instruments that are used in clinical practice [39, 40, 47, 50, 72, 74–76]. The creative imagination of surgeons has led to even using the folding of the chicken skin in various shapes for various urological simulations. Many of these models have the potential for various degrees of face, content, and construct validity as teaching and learning tools in urology (Table 16.2).

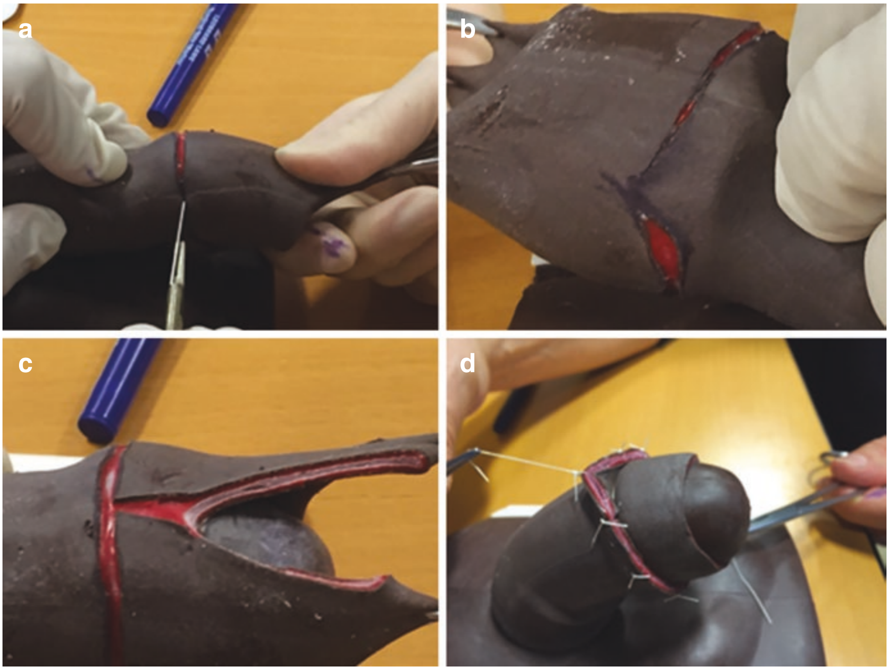

Fig. 16.2 Circumcision model, circular incision on the synthetic foreskin (**a, b**), dorsal slit of the foreskin and demonstration of the inner layer (**c**), suturing of both layers to complete the circumcision (**d**) [25]

Fig. 16.3 Use of a potato to teach basic resection skills in Hawassa Ethiopia [46]

Rapid and precise percutaneous renal access is a challenging step during percutaneous renal surgery [77]. Many bench, animal, and 3D printed models are available to overcome this challenge [78–80]. These have shown that they can improve the efficiency of training punctures in a cost-efficient manner [81]. Both animal and 3D printed models are available; animal models have been rated better than silicon models by users in one study [79]. Training on bench models for ureteroscopy

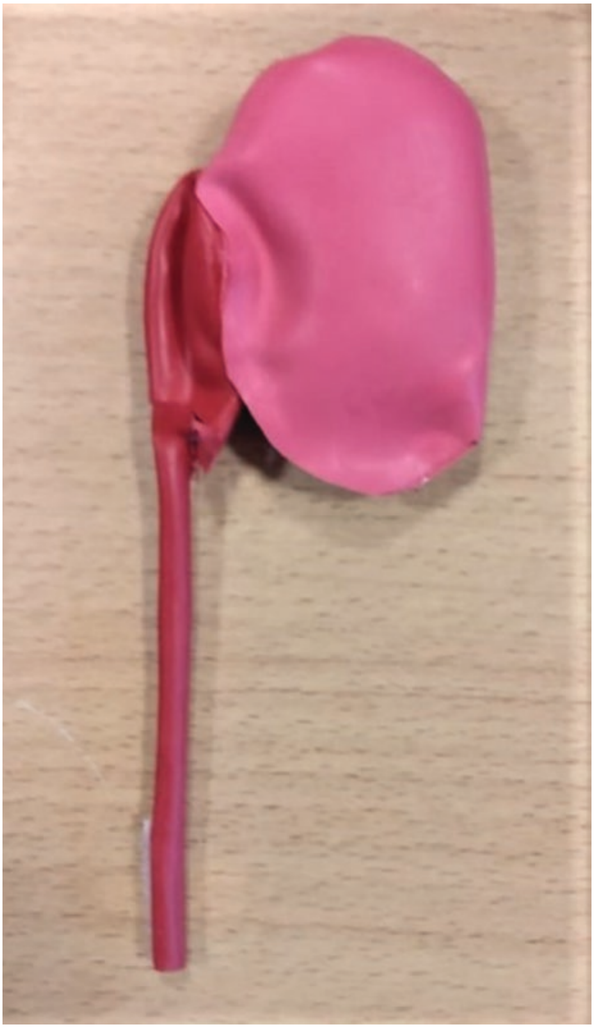

Fig. 16.4 Use of Rubber balloon and tube model for Dismembered Pyeloplasty [61]

allows enhanced manual dexterity as well as familiarity with the method and is recommendable before operating on patients [82, 83]. Similarly, several low-cost, high-fidelity models for pyeloplasty exhibit acceptability and content validity; and improve participant speed (Table 16.2) [64, 65].

The versatility of three-dimensional (3D) printing has a special place in simulations as it allows rapid translation of medical imaging into tangible replicas of patient-specific anatomy, which can simulate the elasticity and mechanical strength of the living organ [84–86]. Its potential has been used for practically all types of urological simulations and showcases its spectrum [84]. However, it is widely considered as an expansive modality for simulation. Paradoxically, it is a great boon for low-cost simulation systems as the actual cost of the models is not much if a 3D printer is already available; which is now available in many educational institutions. Including 3D printed models as low cost is analogous to the use of various expansive operating endoscopes along with imaging modalities while using various low-cost alternatives. Improvements in the science of 3D models are expected to provide even better replication of viscoelastic properties of tissues, various tissue planes and physiological tissue responses to surgical insults, along with more cost-effectiveness [87]. And finally, there is encouraging news on the front of low-cost virtual reality simulation platforms; which will be promising for resource-constrained settings [88].

16.5 Feasibility and Effectiveness of Low-cost Simulating Systems in Urology

Feasibility and effectiveness of low-cost simulating systems on the development of urological skills have been shown in many studies (Table 16.2). Both the low-fidelity, locally made, low-cost trainers and the high-fidelity simulators are equally effective means of teaching basic skills to novice learners [49, 89–93]. In fact, a few studies have found that for basic minimally invasive surgery training, low-fidelity models are superior to high-fidelity models; especially in resource-constrained training programs [94, 95].

16.6 Comparison of Various Simulation Systems

It is important to compare various types of simulation systems to gain a real perspective of what the low-cost alternatives actually offer (Table 16.3) [96, 97].

Table 16.3 shows that the costs shoot up when an attempt is made to upgrade a low-cost training system with high-fidelity physical reality experience, augmented with virtual assessment, explanation of tasks, appropriate feedback, and prompting. Cost is the most important determinant of access to technology and low-cost alternatives will always be needed for those who train and work in resource-constrained milieu. It must be remembered that both low-cost low-fidelity and high-cost high-fidelity systems are a continuum—two ends of the same spectrum—and not dichotomous different approaches [17]. The low-cost system is the more easily and widely available, cost-effective workhorse which can lay the foundation of basic generic surgical skills; over which the edifice of advanced skills can be then easily constructed with high-cost high-fidelity systems [14].

Table 16.3 Comparison of various simulation systems

Simulation model	Advantages	Disadvantages
Cadavers	• Accurate anatomy. • When fresh: gold standard for surgical simulation because of its approximation to living tissue. • Perfused cadaveric tissue creates high-fidelity models.	• Expensive, limited availability. • Require regular maintenance and special facilities. • Formalin fixed cadavers are hard and inappropriate for coelomic simulation. • Not reusable following certain procedures. • Ethical/ infection issues.
Live animals (Wet lab)	• Live experience, may share some features as human surgeries. • Living anatomy and physiology. • Tissue feel and haptics. • Requires adequate control of bleeding, thus replicating human surgery with high-fidelity. • Can practice every element of an operation: technical skills, avoiding complications and their management as and when they arise.	• Possible structural differences between human and animal anatomy. • Ethical concerns over the use of live animals as surgical simulators. • Expensive, requires a big setup, large team including Surgical assistants, Anesthetists, care takers for the animal lab. • Only for single use. • Potential to transmit lethal organisms responsible for zoonotic diseases.
Animal parts (Modified wet lab)	• Economical. • Easy availability from abattoir. • Minimal ethical issues.	• Sterilization requirements need to be strict. • Disposal has to be regulated.
Bench-top and laparoscopic box simulators (Low-fidelity) (Physical reality, PR)	• Allow practice of basic individual skills/ technique. • Economical and simple. • Portable, easy availability. • Multiple uses possible. • For use of novice surgeon.	• Teach “only” basic surgical skills. • May not allow simulation of all steps. • Limited realism. • Lack of interactivity and automated correction advice as seen in virtual reality.
Bench-top 3D printed modules and human mannequin (High-fidelity, Physical reality, PR)	• 3D printing, can accurately recreate complicated procedures under realistic condition. • Largely for advanced surgeons. • Not expensive if a printer is already available	• Expensive than PR, but cheaper than Animal and VR • Limited availability. • Skills difficult to assess.

Table 16.3 (continued)

Simulation model	Advantages	Disadvantages
Virtual reality (VR) simulators	• Create realistic environments that capture minute anatomical details with high accuracy. • Provide explanations of the tasks to be practiced. • Allow practice of a variety of different simulations on a single unit. • Interactivity. • Haptic metrics enable educators to assess trainee's improvement (under research).	• Lack realistic haptic feedback. Expensive. • Limited availability.
Patient-specific augmented reality (AR) simulators, *aka* Mixed reality (MR) as it is a bridge between PR and VR	• Augment pre-operative patient imaging data on top of the patient's anatomical structures. • Retain realistic haptic feedback. Provide objective assessment of the performance of the trainee. • Allows the trainee to use the same instruments that are currently used in the operating room. • Provides realistic haptic feedback.	• Expensive. • Limited availability.
Robot-assisted surgery (RAS) simulators	• Ease-of-use. • Readily available haptic metrics for assessment.	• Very expensive. • Limited availability. • Lack of high-fidelity surgical simulations.

Modified from Sharma et al. [14]

16.7 Low-cost Non-technical Skills Simulation

Non-technical skills (NTS), such as communication, team-work, and task coordination, are increasingly being recognized as vital to patient safety. Many simulation research studies on NTS have shown their educational benefits [98, 99]. High "psychological fidelity" can be ensured at a minimal cost to create a more realistic and acceptable scenario; and low-fidelity simulators have been shown as non-inferior to the more costly high-fidelity simulators for teaching NTS to postgraduate medical trainees [100]. This evidence has been strengthened by the successful delivery of courses for surgeons and anesthetists in Rwanda [101–103]. The success of these programs has led to worldwide interest in developing and teaching NTS to healthcare providers in various specialties including urology [104].

16.8 Limitations of Low-cost Simulating Systems in Urology

Surgical simulation is a "good idea whose time has come" [105]. However, except for a few randomized control trials, most published studies are observational in nature and lack rigorous science [42, 43, 49]. Moreover, most publications have not studied the cost, validity, and educational impact of their low-cost training models in terms of transferability of skills to operating theater (Table 16.2) [37, 38, 76, 106, 107]. This can be easily achieved if the surgeons designing these low-cost simulators do not stop at just designing them but take the extra small step of scientifically validating them [14]. Simulation based urological skills training has been accepted and is being used in various structured "boot-camps," programs, and curricula across the globe [13, 108, 109]. However, greater structured integration in formal training is needed to improve resident skills and ultimately, improve the quality of patient care [110, 111]. The resource constraints of developing countries are well known; however, even developing countries seem to be lagging behind in providing necessary simulation training in urology [11]. Sensitization of trainers is also needed as it is an equally important component for the success of any simulation program. There is no doubt that there is scope of improvement in "refinement of simulation techniques leading to better fidelity, better validation, better incorporation in curriculum, and better availability across the world" [112, 113].

Key Points

- Simulation as a means of learning or rehearsing surgery has a rich history, which is as old as surgery itself.
- Surgical skills, like any other motor skills, can only be acquired by repetitive practice, *i.e.,* simulation; which provides the much needed bridge between theoretical learning and real-life operating experience for a trainee and has become the foundation of modern surgical training.
- Training opportunities in modern surgical skills centers were and are limited due to cost and availability. This has led to the development of low-cost, easily available, and sustainable alternatives for simulation of surgical training.
- A low-cost simulation system has most of the advantages of a high-fidelity system; and in addition is low cost, low maintenance; with easy and cheap construction, so it is accessible to trainees worldwide.
- Several low-cost biological and non-biological models are available for many open, endoscopic, laparoscopic, and robotic urological surgeries.
- Low-fidelity locally made low-cost and high-fidelity simulators are equally effective means of teaching basic skills to novice learners.
- Most publications on low-cost simulating systems in Urology are observational in nature and have not studied the cost, validity, and educational impact in the form of transferability of skills to operating theater. Greater

structured integration in formal training and better availability across the world will improve resident skills and ultimately improve the quality of patient care.
- There is increasing acceptance of teaching non-technical skills in various specialties including urology, with the help of low-cost low-fidelity simulators, which have been shown as non-inferior to the more costly high-fidelity simulators.

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Chapter 17
Learning Non-technical Skills Through Simulation

Craig McIlhenny and Steven Yule

17.1 Introduction

There are many factors which determine the optimal outcome of surgery for a patient, but traditional programs to train surgeons have had an almost exclusive focus on the teaching and learning of the technical skills required to perform an operation. More recently, it has become apparent that possession of good non-technical skills, such as situation awareness, decision-making, team communication, and leadership, is equally important in ensuring safe surgical practice. In this chapter, we define non-technical skills, their importance, and how best to train surgeons in non-technical skills using simulation.

17.2 Surgical Patient Safety

Surgeons take pride in their technical ability to perform an operation, and Birkmeyer has provided good evidence of the link between the level of an individual surgeon's technical ability and patient outcomes [1]. The importance of training in the acquisition of technical skills, and the best and most efficient way to achieve this technical mastery is the subject of an ever expanding body of literature in surgical education, and as this book illustrates, the use of simulation is at the forefront of this new

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paradigm in surgical training. As the reader surveys the chapter list at the start of the book, it is apparent that the focus of much of this research is on the acquisition of these individual technical skills that we are all familiar with.

However, surgeons do not work in isolation, but in dynamic, multidisciplinary teams, often with people they have never met before, in high demand, complex healthcare systems. It is now apparent that within this environment, a surgeon's individual technical ability is not sufficient to ensure an optimally safe outcome for the patient. Although, in the majority of the times, our delivery of surgical care is safe and effective, there is substantial variability in outcomes compared with other industries. In fact, of all hospital inpatients, those requiring surgical treatment have been shown to be at the highest risk of avoidable adverse events.

Gawande, a surgeon from Boston, made one of the first attempts to clarify the source of these adverse events. His paper pioneered the concept that the majority of these adverse events were not due to a lack of technical expertise or surgical skill on the part of the surgeon, finding instead that "systems factors" were the main contributing factor in 86% of adverse events [2]. The most common factors quoted were related to the people involved and how they were functioning in their environment. Communication breakdown was a factor in 43% of incidents, individual cognitive factors (such as decision-making) were cited in 86%, with excessive workload, fatigue, and the design or ergonomics of the environment also contributing. These findings were confirmed in a systematic review of surgical adverse events, where it was found that errors in what were described as "non-operative management" were implicated in 8.32% of the study population versus only 2.5% contributed to by technical surgical error [3].

In accordance with other high-risk industries, such as commercial aviation, the majority of these adverse events are therefore not caused by failures of technical skill on the part of the individual surgeon, but rather lie within the wider healthcare team, environment, and system. Lapses and errors in communication, teamworking, leadership, situation awareness, or decision-making all feature highly in the analysis of surgical adverse events. So, while we expend time and energy training our future surgeons in the technical ability to perform an operation, the literature clearly tells us that this is not sufficient, and that a focus on training on the so-called non-technical skills is also required to provide safe surgical care. This knowledge of the importance of non-technical skills (NTS) has been prominent and acknowledged in most other high-risk industries for many years, but it is only recently that healthcare has appreciated this.

17.3 Non-Technical Skills

Non-technical skills (NTS) are those skills that are distinct from the pure technical ability to perform the operation and are defined as the cognitive and social skills that characterize high-performing individuals and teams. Non-technical skills are not new skills; they are intrinsic to everyday work. They are related to how we do everyday things—reach diagnoses, make decisions, interact with colleagues, deal with stress—to maximize safety and efficiency. You will have encountered surgeons that are very good at anticipating and managing problems; they share the plan with the team and always seem in control. You may also have encountered others who always seem to run into difficulties, lose their temper, and expect things to be done without having asked. Each of these scenarios is a reflection of good and poor non-technical skills, respectively. Optimizing individual and team performance via enhanced non-technical skills can result in improved decision-making, increased efficiency, higher adherence to safety standards, greater resilience, and better outcomes. In this section, we describe the specific behavioral and non-technical skills for the operating theater that have been shown to reduce performance errors and save lives.

Within the surgical domain, the tool with the most validity evidence for teaching, classifying, and assessing NTS is the Non-Technical Skills for Surgeons (NOTSS) system (see Fig. 17.1) [4, 5]. The NOTSS system describes an individual surgeon's non-technical skills in four domains. Two of these domains are cognitive, i.e. using your brain, and are named "situation awareness" and "decision making." The other two domains are described as social categories and these look at the individual's relation to the rest of the surgical team, namely "Team Communication" and "Leadership."

As the reader may not be familiar with the language of non-technical skills, we shall examine each domain in turn:

17.3.1 Situation Awareness

Arguably the most critical non-technical skill, situation awareness, is required for accurate decision-making, timely communication, and appropriate leadership. For the operative environment, situation awareness is defined as: "Developing and maintaining a dynamic awareness of the situation in the operating theatre, based on

Category	Elements
Situation Awareness	• Gathering information • Understanding information • Projecting and anticipating future state
Decision-Making	• Consider options • Selecting and communication option • Implementing and reviewing decisions
Communication and Teamwork	• Exchanging information • Establish a shared understanding • Co-ordinating team activities
Leadership	• Setting and maintaining standards • Supporting others • Coping with pressure

Fig. 17.1 The non-technical skills for surgeons (NOTSS) system. See also www.notss.org

assembling data from the environment (patient, team, time, displays, equipment); understanding what they mean, and thinking ahead about what may happen next." Situation Awareness comprises three distinct levels: (i) Gathering information, (ii) Interpreting the information (based on experience); and (iii) Projecting and anticipating future states.

Best practices for situation awareness

- Check back for important information
- Provide periodic status updates
- Share what will likely happen in the near future so others can plan

17.3.2 Decision-Making

Surgical decision-making can be defined as "Skills for diagnosing a situation and reaching a judgment in order to choose an appropriate course of action." Classical models of decision-making propose an analytical process: the relative features of options are compared in turn and an optimal course of action is selected. However, this is an effortful process, requiring both experience and time to come up with an acceptable solution. Rule-based decision-making can be used effectively by novices and experts alike; once a situation has been detected, a relevant rule can be applied, either by following national guidelines or local protocols. Experts tend to use a more heuristic-based style called "recognition-primed decision making" (RPD); a type of pattern matching used to make satisfactory decisions under times of high stress or time-pressure. As there are not always prior experiences from which to work, surgeons may use creative decision-making when a totally novel solution is required to treat patients or develop new processes of care.

Best practices for decision-making

- Gather sufficient data to make decisions
- Do not delay in order to have the complete picture
- Offer potential solutions

17.3.3 Team Communication

Effective team dynamics are essential for rapid diagnosis, concurrent treatment, and containment of risk. They are also essential for the vast majority of surgical practice and essential for experienced and novice surgeons alike. Communication and teamwork are the skills required for working in a team context to ensure that the team has an acceptable shared picture of the situation and can complete tasks effectively. What is essential is that each member of the team has a "shared mental model" of both what is happening and what is the planned outcome. There are many barriers to communication, which can be both internal and external. Closed loop communication can reduce communication errors by making certain that all members of the care team clearly and effectively share information with one another in a structured manner. We will describe other structured communication tools later in this chapter.

Best practices for team communication

- Introduce yourself and your role to the other team members
- Be clear and concise
- Do not assume team members have heard you if they do not acknowledge

17.3.4 Leadership

In organizations exposed to hazards, there is widespread recognition that leadership is essential for efficient and safe team performance. Surgery is no different, and although surgeons are often leaders, the situation in the operating room is often not a clear hierarchy, with anesthetists, nurses, and other colleagues often taking leadership roles and displaying leadership behaviors. Surgeons may normally be used to autonomous practice, but they can contribute to effective teamwork by demonstrating shared leadership or assuming followership in certain situations. A core function of leadership is demonstrating the standards that are expected from other team members. A key failing of leaders is to emphasize the importance of safety but then implicitly undermine those sentiments by breaking rules and not adhering to high standards of ethical and professional conduct themselves. For surgeons, examples of this are adhering to guidelines regarding antibiotic use, respecting sterility protocols, and being transparent regarding errors, even during surgical emergencies. Surgeons exert leadership by coping with pressure and by keeping composure even in the most difficult of times.

Best practices for leadership

- Set expectations on roles, culture, and norms of behavior
- Listen to the concerns of others and validate them
- Active engagement in conflict resolution

17.4 The Importance of Non-Technical Skills

While in comparison to other high-risk industries, the appreciation of the importance of NTS is in its infancy, there is nonetheless a growing interest and body of research confirming the importance of non-technical skills in surgery. As previously mentioned, a systematic review from 2013 incorporating over 16,000 surgical patients found an adverse event rate of 14.4% and that while errors in surgical technical skills accounted for 2.5% of those errors, lapses in non-technical skills accounted for 8.3% of these adverse outcomes.

A study of pediatric cardiac surgery teams rated a team's non-technical skills, and found a strong correlation between the quality of the teamwork and both the duration of surgery and the rate of problems arising during the procedure [6]. Similar investigations in adult operating rooms rated teamwork in surgical teams using a unique behavioral marker system and found that when teams deployed poor non-technical skills related to teamwork, their patients were more likely to experience death or major complications. In this study, the level of teamworking was a much more powerful predictor of poor patient outcome than the ASA grade of the patient [7].

17.5 Simulation Training for Non-Technical Skills

It is now clear that for surgical care to be performed safely and effectively, the surgeon and the wider surgical team must be proficient in the non-technical skills described previously. As with the acquisition of technical skills this will require deliberate practice and training in these NTS, but to date, this has not been commonplace in surgical training programs, which have tended to be centered around the acquisition of knowledge and technical skill only. This position is now being altered as a number of training and regulatory bodies are now recognizing and emphasizing the need to focus on NTS during surgical training programs.

With the understanding that it is no longer acceptable to achieve clinical proficiency by practicing on patients, simulation constitutes one of the fastest growing training approaches to emerge in recent years. Simulated learning environments provide a safe environment to practice technical skills, gain initial experience of complex technical challenges, and make mistakes without harming patients. Reduced working hours and advances in technology have aided this growth, and in the USA, access to simulation for training is a requirement for the American College of Surgeon (ACS) accreditation. There are many applications of simulation methods for training individual technical skills and team non-technical skills [8]. Modalities range from ultra-realistic mock-operating rooms with the capability to recreate surgical emergencies for a fully immersive learning experience, to simple box trainers to allow surgeons to hone and master the knowledge, judgment, and technical skills required for laparoscopic surgery. Robotic surgical simulators have emerged in recent years to facilitate the admission of new technology, and the "igloo" [9] has been deployed for urological surgical simulation, allowing a portable immersive environment for training.

Non-technical skills are trained and assessed in a variety of ways, involving standardized patients to assess trainees' interpersonal and communications skills; and team training exercises to examine teamwork, leadership, and situation awareness. Debriefing after simulation training is essential for learners to understand each others' frames allied to the learning objectives of the course [8, 10].

The dominant finding of systematic reviews in this area is that non-technical skills can be improved through simulation training, and that both high-fidelity operating room or lower fidelity courses are effective. High-fidelity simulation followed by debriefing sessions has been found to be superior to didactic and practice alone at skill acquisition [11]. Effectiveness has been primarily measured by behavior change and other process measures—evidence is still lacking for impact on patient outcomes. Now that mature training curricula are being developed, more sophisticated randomized prospective trials could be designed to show an impact on patient outcomes. One such non-simulation design involving team training at over 100 USA hospitals showed a significant improvement in mortality for hospitals who were involved in non-technical skills training vs. a control group [12]. For recent literature on surgical training in non-technical skills, there is an excellent systematic review [13].

17.6 Non-technical Skills in Urology

The aim of any training program in urology should be to produce competent and safe urological surgeons. Our philosophy is that training a surgeon purely in the technical aspects of surgery is not sufficient, and that any training program should train surgeons in all aspects of non-technical performance. While the majority of simulation-based training programs have traditionally focussed on the development of surgical techniques, the recent realization that technical ability is necessary but not sufficient for the delivery of safe surgical practice has led to non-technical skills being emphasized and incorporated into simulation training programs. The current state of practice, availability of evidence, and research in this area of non-technical skills (NTS) training does, however, have a significant lag compared to the arena of technical skills performance. Within this section, we will examine the existing literature, looking at evidence for the evaluation and outcomes related to non-technical skills in urology and also how these might best be trained and incorporated into urology training programs.

A survey of both trainees and trained urologists in the UK confirmed the learning need for more non-technical skills training. In this survey, only 41% of urological trainees felt that their NTS training was sufficient to prepare them for safe independent practice [14]. A total of 28% of the trainees surveyed reported that they had no simulation training at any point in communication/teamwork and 35% reported no decision-making simulations during their training programs. Clearly, NTS training must improve further, and there is a need for the incorporation of standardized and validated curricula in urology.

17.7 Simulation to Teach Non-Technical Skills in Urology

The literature in training modalities for non-technical skills in the domain of surgery is still relatively sparse, and even more so within the sphere of urology. A 2019 systematic review of NTS training in surgery [13] identified 28 articles for inclusion, of which seven were urology based. Four different methods of training non-technical skills—classroom-based or didactic teaching, low-fidelity simulation, high-fidelity simulation, and Crisis Resource Management (CRM) were identified.

Furthermore, Griffin et al. summarized non-technical skills training and evaluation in urology—in a literature review rather than a systematic review [15]. They acknowledged that didactic or classroom teaching can be useful for introducing NTS concepts and there is evidence from a study of medical students who improved their teamwork, situational awareness, and ability to handle errors after a single didactic classroom session compared to a control group. However, simulation is the most effective way to train NTS and is superior to didactic lectures for enhancing skills as wide reaching as technical ability, decision-making, and breaking bad news. Similar to the review by Ounounou, Crisis Resource Management (CRM) simulation modalities are divided into Distributed Simulation (DS, including low fidelity simulation), and high fidelity OR simulation (HFORS), a structure that we will use to explore the evidence for NTS in urology in the following sections.

17.7.1 Distributed Simulation

Distributed simulation (DS) is simulation on-demand, made widely available wherever and whenever it is required. The advantage of DS is that it provides an easily transportable, self-contained "set" for creating simulated environments, at a fraction of the cost of dedicated, static simulation facilities [16].

DS has also been referred to as "low fidelity simulation" by aiming to deliver as high a fidelity experience as possible to the participants but within a portable and accessible environment. The most commonly described form of the distributed simulation was devised by a group from Imperial College in the UK. This consists of a 360-degree inflatable enclosure or "igloo" which can be sited in practically any open space. The enclosure is then populated with a mixture of real equipment as needed for the scenario but also with simulated equipment such as poster banners with life-like representations of real-world equipment but that is not required to function for the purposes of the training. Within this environment, Kassab developed and validated Distributed Simulation using a simulated laparoscopic cholecystectomy as the index operation and, using a mixed methodology, found that the environment felt realistic and was perceived good for training [17]. DS also showed construct validity in technical skills training for laparoscopic cholecystectomy, as experts outperformed novices in this environment.

The use of low-fidelity simulation and distributed simulation has been used extensively by the King's College London Group. Brewin et al. studied ten trainees and ten experienced urologists performing a transurethral resection of the prostate (TURP) in the DS environment to ascertain whether the use of distributed simulation was valid and examined face validity, content validity, and construct validity [18]. Face and content validity were evaluated using qualitative questionnaires, and the results confirmed both face and content validity. The non-technical skills of both groups were assessed using the NOTECHS scale, and the non-technical skills of the experienced urologists were found to be significantly better than those of the trainees, establishing construct validity. Demonstrating that low-fidelity simulation could still feel psychologically real, participants reported that the environment was realistic enough with sufficient clues to be perceived as realistic, evoking the feelings and behaviors of the real OR from participants.

Brunckhorst et al. also used distributed simulation to examine the technical and non-technical urological skills of 32 medical students [19]. This is a comparative study of simulation vs. non-simulation training (knowledge only). Half of the medical students had technical and non-technical skills training within a simulation-based rigid-ureteroscopy curriculum, and the other half only received a short didactic introductory session. All of the technical skill parameters analyzed demonstrated a significant correlation with NTS measured using the NOTSS rating scale. The intervention group also demonstrated a significant negative relationship between time to completion of the simulated ureteroscopy and communication and teamwork, situational awareness, and decision-making ($p < 0.05$). We can conclude from this study that simulation training can increase the speed and efficiency of skills.

The same group carried out a randomized controlled trial assessing the effectiveness of a simulation-based ureteroscopy training curriculum integrating both technical and non-technical skills [20]. Thirty-two medical students were randomized into the intervention arm or control arm. Those in the intervention arm underwent full ureteroscopy training utilizing a curriculum combining didactic teaching with simulation practice in the "Igloo": a distributed simulation environment (see Fig. 17.2). The intervention group was found to have higher NOTSS scores than the control group, and interestingly, it was also found that participants who had any previous training within the DS environment demonstrated significantly improved NOTSS scores. Eighty-six percent of experts agreed that the developed curriculum would be effective in teaching ureteroscopy to novices.

Fig. 17.2 The Igloo: a distributed simulation environment

17.7.2 High-Fidelity Operating Room Simulation (HFORS)

High-fidelity simulation is often thought of as the “gold standard” for immersive surgical training. In the healthcare simulation dictionary, high-fidelity refers to simulation experiences that are extremely realistic and provide a high level of interactivity and realism for the learner. HFORS has been described as essential in the development and practice of non-technical skills and trainees agree that it resembles close to real life as most studies demonstrated face validity. High-fidelity operating room simulation takes place either in a dedicated simulation center or facility or in an actual operating theater with observation and debriefing as core components of learning (Fig. 17.3). This makes the simulation highly realistic but also expensive in terms of dedicated faculty and real estate. As well as being an effective training method, high-fidelity simulation has also been shown to be useful for the assessment of non-technical skills, as we will learn in the following sections.

Within the field of general surgery, evidence exists for the use of high-fidelity simulation to train and improve non-technical skills. Rao et al. used a high-fidelity OR setup to train 15 general surgery residents performing simulated gastrojejunostomies both before and after using three team-based tasks designed to teach communication and teamwork [21]. The post-intervention assessment demonstrated improved NOTSS scores as well as a concomitant increase in technical skills, as measured by OSATS [22].

Within the urology domain, Abdelshehid et al. conducted a prospective cohort study in a HFORS environment, in which nine urology trainees undertook a laparoscopic partial nephrectomy scenario, using validated simulator models [23]. The scenario incorporated two scripted events: an anaphylaxis event and a patient

Fig. 17.3 Observation of operating room team training with simulation at the STRATUS Centre for Medical Simulation, Brigham & Women’s Hospital, Boston, USA

identity error. The scenario was video recorded and reviewed by two trained and blinded reviewers using the NOTSS assessment tool. Following the simulation, a debriefing session was held with all participants. The investigators found that the level of urology resident training correlated positively and significantly with non-technical performance using the NOTSS score, thus showing construct validity. There was, however, no intervention or pre- and post-test in this study, but the trainees “felt this training was useful.”

Lee et al. conducted a study similar to Abdelshehid whereby urology trainees undertook a simulation-based scenario for a laparoscopic nephrectomy alongside trainees in anesthetics [24]. Sixteen urology residents were randomly paired with anesthetic residents to participate in a simulation-based team training scenario involving the management of two scripted critical events during laparoscopic radical nephrectomy, including the vasovagal response to pneumoperitoneum and renal vein injury during hilar dissection. A debriefing session followed each simulation-based team training scenario. The scenarios were videoed and assessments of technical and non-technical performance were made using task-specific checklists and NOTSS by four expert faculty.

The vast majority of the participants (94%) rated the simulation scenario as useful for training communication skills and said it should be included in their training program. For the urology residents, the year of training correlated positively and significantly with technical performance and blood loss during renal vein injury management but not with non-technical performance. Urology trainees consistently over-rated their non-technical skills by rating themselves higher on non-technical performance than the experts rating them, whereas the anesthetic trainees did not differ in their self-assessment of non-technical performance compared to faculty assessments.

Goldenberg et al. also reported on using high-fidelity simulation to develop an assessment of urology trainees’ non-technical skills [25]. This study involved 15 urology residents who took part in a simulated laparoscopic nephrectomy with a vasovagal response to insufflation and then a vascular injury scenario. The scenarios were videoed and then assessed for both technical and non-technical skills by expert observers using GoALS and NOTSS, respectively.

While this study again had no intervention or control group, they reported that more senior trainees demonstrated higher technical and non-technical skills than their junior counterparts, and that overall technical scores correlated positively with non-technical scores.

One study which did report the effect of an intervention to improve NTS in urology was carried out by Gettman et al. Seventeen urology residents participated in a prospective simulation study performed again in a high-fidelity OR environment [26]. This was a before and after study where trainees participated in a team-based scenario with a simulated laparoscopic crisis, such as CO_2 embolism or insufflator failure. The trainees then underwent training in teamwork and communication before participating in a second different scenario. The participants were debriefed using recorded videos of the scenarios they took part in, and their teamwork skills were evaluated by experts.

After the scenario, participants filled in Likert questionnaires, which confirmed both face and content validity. This study reported significant improvements in teamwork scores between the first and second scenarios and concluded that "high-fidelity simulation was effective for assessing and teaching core competencies related to intraoperative communication, teamwork and laparoscopic skills."

Shamim Khan et al. studied 33 urology specialist registrars of different grades participating in CRM sessions as part of seven full-day programs [27]. The scenarios consisted of the trainees in an HFORS environment followed by a structured debrief led by faculty. Non-technical skills were not formally assessed, but face and construct validity were established from an overwhelmingly positive response from the interviews and questionnaires conducted.

17.8 Robotic Surgery

Urological surgery tends to reside at the envelope of technological innovation. One such example is the widespread uptake of robotically assisted surgery, which is often now the norm for urological procedures such as radical prostatectomy or partial nephrectomy.

Robotic surgery is significantly different from traditional open surgery, however, with the main surgeon immersed in the console and remotely located from the patient and the surgical team (Fig. 17.4). It has been suggested that robotic surgery may require an even greater command of non-technical skills, and that some of these non-technical skills may be unique to the robotic surgery milieu [28].

Fig. 17.4 Robotic simulation

A prospective observational study involving five French urological surgery departments was reported by Manuguerra et al. [29] Trained non-technical skills experts observed and filmed 27 live robotic procedures. The experts used a non-technical skills in robotic surgery score and found the median score to be only 18 out of 40 (range 10–25). For the observed surgical teams, safe communication was assessed to be "very poor" in 61% of cases, with situation awareness likewise noted to be poor in 69% of cases, mainly due to a lack of anticipation and not sharing information with the team. For these 27 procedures, a median of 9 near miss events per procedure was observed, and the number of near-misses was closely negatively correlated with the non-technical skills score. The procedures were all performed by experienced surgeons, but there was no correlation between the surgeons' experience or the number of near-misses or non-technical skills score. Interestingly, 58% of the surgeons thought there was no need for improvements to their own or their teams' non-technical skills.

While the above study demonstrates that non-technical skills require improvement in robotic surgery, and that poor non-technical skills lead to more near misses, there were no outcome measures examined. In another study, Sexton et al. analyzed 12 video recorded robot-assisted radical prostatectomies and looked specifically at communication between the surgeon and the team members and found that better communication and teamwork led to reduced surgical time (overall 8% reduction in time) [30]. They also found that increased cognitive load for the surgeon decreased the effectiveness of communication and teamwork. Other than operative time, no other outcome measures were examined.

While the NOTSS taxonomy is validated for surgery, it is not specifically designed for robotic surgery. A new system that is expressly designed for robotic surgery, ICARS (Interpersonal and Cognitive Assessment for Robotic Surgery), has shown reliability on initial validity testing and may be suitable for incorporation into future curricula [31]. It is similar to NOTSS but includes additional domains for console setup, World Health Organization surgical safety checklist completion, and management of stressors and distractors.

The current literature examining non-technical skills in robotic surgery, therefore, demonstrates that non-technical skills in robotic surgery are as important, if not more important, than in traditional surgical settings. There is a clear demonstration of the need for improved NTS in robotics and potential human factors challenges of the technology [32]. At present, there are no studies looking at the effects of training of NTS in robotics.

17.9 Ward Rounds/Other Environments

Surgeons do not spend their time entirely within the operating theater domain, and there is increasing evidence for the importance of non-technical skills in other healthcare environments. Within the urology sphere, a group from Leeds, UK has examined the domain of the ward round [33]. This study involved 48 junior urology trainees attending a "boot camp" and utilized a high-fidelity approach to a simulated ward round hosted within a real ward environment with actors as patients. Received feedback from the trainees was positive for this type of training but no interventions or pre- and post-testing were reported.

17.10 Transfer and Retention of Knowledge

Transfer validity and skill retention are particularly difficult to investigate since following up participants is logistically challenging, resulting in many studies lacking these important data. Studies which do follow up participants show NTS retention for at least 2 months in current training programs, in which some claim trainees are still benefitting at 6 months, but others note that there is no significant difference between the NOTSS scores of surgeons who have previously undertaken NTS training versus those who have not. These studies often employ a second simulation session to record improvement and do not look at real performance in the OR. The longer-term effects of any course are yet to be shown, but repeat training is necessary to maintain skills after they are learnt initially and make sure they translate to practice. This poses two unanswered questions: how frequent should NTS training be and how should "refresher" courses be structured?

17.11 Recommendations

For urologists to perform safely and effectively, and to optimize outcomes for their patients, it is now clear that pure technical skill is necessary but not sufficient, and that the application of good non-technical skills is also required. This acquisition of non-technical skills will require training and deliberate practice, as is the case with technical skills. While most urology training programs have traditionally had an almost exclusive focus on surgical technical skills, a number of regulatory and accreditation bodies are now emphasizing the importance of NTS training. However, formal training in NTS remains in its infancy and is not comprehensive or universal. There, therefore, remains a significant challenge of creating appropriate curricula that allow NTS to be fully integrated into all surgical training programs. While a full discussion of the implementation of NTS training is beyond the scope of this chapter, but we present some principle recommendations on how this should be approached.

Demonstrating high levels of competence in NTS should be expected and required at all stages of a surgical career, and as happens in commercial aviation, these NTS should be formally taught and assessed for progression and licensure. In order to achieve this, NTS training requires to be fully integrated into existing urology training programs such that it is taught throughout training and given the same emphasis as training in technical skills.

To introduce NTS concepts, teaching should initially be classroom-based; this will allow trainees to learn both the importance of non-technical skills and an appropriate taxonomy such as NoTSS. Once this basic level of knowledge acquisition is completed and there is proficiency in basic non-technical skills, an appropriate form of simulation can be undertaken. The form of simulation best suited to each training program is likely to depend on the local availability of facilities and faculty, but the current evidence within urology suggests that both distributed simulation and high-fidelity OR simulation are effective, at least at Kirkpatrick levels 1, 2, and 3, but further research in this area should be encouraged and welcomed.

17.12 Conclusion

NTS training has come a long way in the past decade, with many more courses offered for trainees and better validated training tools. The evidence points to simulation training as the most effective way to train NTS. However, a standardized surgical NTS curriculum is still lacking, facing logistical challenges alongside the issues of determining optimum training methods and testing validity. Despite this, there are behavior evaluation tools with extensive validity evidence such as NOTSS to help structure training and evaluation in urology, and with a growing faculty with experience of non-technical skills, there are many future opportunities for integrated training and assessment in simulation which will protect patients, support lifelong learning, and inspire the future generation of urologists to even higher levels of performance.

Key Points

- Good non-technical skills are as important as technical ability in ensuring optimal patient outcomes.
- The NoTSS system is the most validated for teaching and assessing non-technical skills.
- Simulation is the best way to train non-technical skills.
- Further work is needed to develop a standardized non-technical skills curriculum.

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Chapter 18
Basic Skills Training in Robotic Surgery: Dry and Wet-Lab Models and Their Application in Robotic Training Pathways

Elio Mazzone, Paolo Dell'Oglio, and Stefano Puliatti

18.1 Introduction

During the last two decades, robotic surgery has become the most widely used approach for oncological surgery [1]. Moreover, considering this technical transformation and the need to rapidly introduce novice and expert open surgeons to these new systems, training in robotic surgery has become a hot topic of discussion in the literature [2]. In this context, the time to achieve the necessary skills to perform a procedure and to accomplish an optimal performance follows a learning curve, which is the mathematical graphical representation of the improvement of surgical outcomes with increasing surgical experience [3]. Unfortunately, during the initial phase of the learning process, the possibility of experiencing complications and negative postoperative outcomes may not be negligible and may, in consequence, increase the risk of harming the patient and decrease patient's safety [4].

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Moreover, the need for adequate training faces restrictions due to reduced working hours and ethical considerations, which increasing the difficulty of training [5–7]. Therefore, multiple robotic surgery training methods have been proposed to reduce the length of the initial learning curve phase and to progressively increase the trainee's responsibility with minimal impact on the patient's outcomes. In this context, the historical Halstedian training model ("see one, do one, teach one") is outdated, and the new surgical learning methods are needed [8]. As a consequence, a new validated and objective proficiency-based progression (PBP) training methodology needs to be fully introduced in a preclinical setting [9].

The scientific societies are now facing the ethical and practical challenges to search for alternatives to train surgeons through the simulation of surgical processes in the laboratory prior to contact with a patient in the operating room, in a safe learning environment to minimize the risk of errors [8, 10]. As previously reported, this preclinical training should always be included in a standard robotic surgery curriculum [11–13]. Based on this premise, a variety of dry- and wet-laboratory models, including box trainers, animal models, and human cadaveric models, have been developed and are increasingly used during the last few years. They can be implemented during the learning pathway because each one of them has specificities that allow their simultaneous use in a step-by-step training program. However, some training models (e.g., virtual reality simulators or chicken models) are better designed to teach basic surgical tasks and primarily ablative techniques, while others (e.g., porcine or human cadaveric models) are fit to train more complex procedures [14–16]. This chapter focuses on the role played by virtual reality simulators and dry- and wet-laboratory models in teaching basic surgical skills in robotic surgery. Specifically, we will provide an overview of the different models available for the basic skills training and their application in the robotic training curriculum for basic surgical skills.

18.2 Main Body of the Chapter

18.2.1 The Role of Simulation Training in Robotic Surgery

Simulation training introduces trainees to new technologies and instruments and allows the improvement of surgical psychomotor and visuospatial skills. It also allows the repetition of a task and can be interrupted as needed, providing an opportunity for immediate feedback. It has been reported that the early use of any simulator is associated with reduced training costs, by its impact on patient safety, and with a rate of error reduction [17, 18]. In other medical fields, such as interventional radiology or central venous catheter insertion, simulation training has proven to reduce complications [19, 20]. This essential step has been demonstrated that it can be retained over time, even if surgeons do not practice minimally invasive surgery for up to 2 years [21]. Moreover, thanks to the application of standardized platforms with objective evaluation, the use of simulation training may be applied to record that a trainee has attained the prescribed level of proficiency and has achieved enough surgical skills for a specific task/procedure. This method has been introduced in different surgical examinations such as the ESU-initiated European Basic Laparoscopic Urological Skills (EBLUS) and the Fundamentals of Robotic Surgery (FRS) [22–24]. However, before starting with practical tasks focused on the acquisition of basic surgical skills, a robotic training pathway should start with learning the necessary theoretical knowledge about the surgical system that will be used. A trainee should become familiar with the robotic technology by learning the specific robotic device's functions (also known as "instructions for use"). This technical training is of the utmost importance. Instructions on troubleshooting and the limitations of the operating system are an essential part of the training. To achieve this goal, online modules and practical hands-on training sessions are available to introduce the basic concepts of the only commercially available systems. Certification in these online and practical modules is essential before starting any surgical skills training [2, 9, 25, 26].

After a trainee is well trained on the robotic platform, training on basic robotic skills can be initiated. The first step consists of performing dry-lab exercises on inanimate bench-top models and virtual reality (VR) simulated environments. As for the technology training, the basic skills training should be introduced through an e-learning module showing all the necessary steps that have to be performed in the different tasks. These exercises are important in achieving basic and advanced console skills and improving coordination development, bi-manuality, dissection, and suturing techniques. VR-simulators and other dry lab models are usually inexpensive to run, well-tolerated, convenient, and efficient [2, 27, 28]. However, the exercises that can be performed with dry lab simulators lack bleeding and do not compare with real-life surgery. Therefore, wet-lab models represent the next step in training to consolidate basic surgical skills that are acquired in the dry lab. In the wet-lab laboratory, surgical techniques are trained on cadaveric (i.e., canine model) or live animals (i.e., porcine model) or human cadavers. These anatomical models are more comparable to a real-life setting, allowing trainees to interpret the robustness and consistency of animate tissues, as well as to simulate complete surgical procedures and emergency scenarios, such as vascular/organ injuries repairs. However, wet-lab models imply higher costs and require sacrificing large number of animals [2, 27, 28]. After completing all the different modules for basic skills training, trainees should undergo a final evaluation that certifies the acquisition of proficiency. Only after a positive evaluation, the trainee can proceed with his procedural or advanced training.

Available simulation training models for basic robotic surgery skills can be categorized as follows:

18.2.2 Basic Training Models

18.2.2.1 Virtual Reality Simulators

VR consists of a simulated model, designed by software, that can represent a complete surgical procedure or a simple exercise that is designed to improve a specific technical skill. VR has the advantages of having high availability to use the simulator, without the use of disposable materials and with minimal supervision needed. It offers the possibility of analyzing and scoring the performance of trainees' procedural skills using objective and transparent metrics. Despite the potential advantages, the main limitations are the high initial cost and the inability to achieve a level of realism comparable to a real-life case. However, the improvement of the graphic designs and the recreated feedback can turn virtual reality into the ideal method to improve technical skills in robotic surgery [23, 29].

Evidence suggests that simulators should be integrated into proficiency-based training for basic robotic surgical skills and procedural tasks prior to independent practice, since training on VR consoles may improve performance in real life [18, 30]. However, there is a lack of strong evidence on the predictive validity of the simulators, i.e. the application of skills gained using simulators to real-life robotic surgery [27, 31, 32].

The first VR robotic surgery simulator was introduced in 2010. To date, six VR simulators are commercially available for robotic surgery training: the da Vinci Skills Simulator (by Intuitive Surgical, Sunnyvale, USA), the Robotic Surgical Simulator (RoSS) (by Simulated Surgical Systems, Buffalo, USA), the SimSurgery Educational Platform (SEP) robot (by SimSurgery, Norway), the da Vinci (dV)-trainer (by Mimic Technologies Inc., Seattle, USA), the ProMIS (Haptica, Ireland), and the RobotiX Mentor™ (by 3D Systems, Israel) [27, 31, 33, 34]. All these simulators underwent evaluation of their validity in different studies. Different degrees of validation are possible [27, 31, 35, 36]:

– ***Face validity:*** the extent to which the simulator resembles a real-life situation. This is generally determined by a group of experts.
– ***Content validity:*** the extent to which the skills test by the simulator accurately represent the skills required in robotic surgery.
– ***Construct validity:*** the extent to which the assessment exercise measures the intended content domain or the extent to which the simulated task discriminates between operators of different levels of surgical skill.
– ***Discriminant validity:*** the extent to which a simulator is able to differentiate between ability levels within a group with similar experience.
– ***Concurrent validity:*** the extent to which the simulator scores and actual robotic scores are comparable for a similar task.
– ***Predictive validity:*** the extent to which the performance on the simulator predicts future performance on the robotic platform when used clinically.

All simulators (regardless of add-ons) have been evaluated to have face, content, and construct validity, except for RoSS which lacks construct validity [27, 37]. The most frequently used simulator today is the da Vinci Skills Simulator (dVSS). This simulator is a customized computer package that runs on the actual surgical console. It exists for both the X and the Xi da Vinci systems and offers basic to advanced training modules [35]. The simulator allows instant feedback with an overall score that takes into account performance efficiency measured according to time, movement economy, and penalty metrics. Modular training add-ons for specific complex procedures, such as radical prostatectomy and hysterectomy, are also available. Face, content, construct, concurrent, and predictive validity have been proven in the literature [33, 35, 38–40].

The Mimic dV-Trainer (MdVT), RoSS, and RobotiX Mentor™ are stand-alone VR robotic surgery simulators that mimic the dVSS. All three simulators offer multiple basic to advanced training modules with comprehensive performance metrics, evaluated by an automated, integrated system [26, 33, 35, 41–45]. MdVT, RoSS, and the RobotiX Mentor™ offer procedure-specific modules in which trainees interact with a 3D VR anatomical environment. Maestro AR, the procedure-specific add-on of the MdVT, offers training for right partial nephrectomy, hysterectomy, inguinal hernia repair, and radical prostatectomy for da Vinci Si, X, and Xi systems [27, 33]. The Tube 3 module of the MdVT is specifically designed to train the vesicourethral anastomosis, allowing therefore to improve the performance of trainees in one of the most complex steps in robot-assisted radical prostatectomy [33, 44]. The Hands-on-Surgical Training (HoST) add-on of RoSS offers training in radical hysterectomy, radical prostatectomy, radical cystectomy, and extended lymph node dissection [27, 33]. The RobotiX Mentor™ offers training in complete surgical procedures such as radical prostatectomy, hysterectomy, lobectomy, inguinal hernia repair, and right hemicolectomy [33, 45, 46]. Both the RobotiX Mentor™ and the MdVT offer a laparoscopic assistant component in parallel with the VR console. This allows simultaneous training of both the surgeon and bedside assistant, improving coordination, communication, and teamwork. For the MdVT, this is a specific add-on called the Xperience Team Trainer [27, 33, 47–49].

The SEP Robot and the da Vinci-ProMIS surgical simulator are two robotic surgery simulators that are modifications of previous laparoscopic versions. In these simulators, the basic laparoscopic instruments have been replaced by the wristed instruments with seven degrees of freedom of the da Vinci Robot. The SEP robot is a VR simulator that offers different exercises where trainees are evaluated based on instrument tip trajectory, time, and error scores [50]. Although being a cost-effective alternative to other simulators, SEP has a few shortcomings: it does not offer the possibility to train clutching, needle control, and driving or dissection exercises as in other simulators. Furthermore, a fourth robotic arm, three-dimensional images, and performance feedback are also not available in SEP [26, 33].

The Da Vinci-ProMIS surgical simulator is a hybrid simulator in which the dVSS is docked to the ProMIS bodyform, a plastic mannequin covered with neoprene. Three camera tracking systems detect the instruments inside the simulator, offering an evaluation of time, the economy of motion, and instrument path length for both virtual and physical training models [33, 51]. The status of the validation of all virtual reality robotic surgery simulators is summarized in Table 18.1.

Table 18.1 Overview of currently available robotic surgery simulators and add-ons and the status of their validation

Name	Face validity	Content validity	Construct validity	Concurrent validity	Predictive validity
da Vinci Skills simulator (dVSS)	Yes	Yes	Yes	Yes	Yes
Mimic dV Trainer (MdVT)	Yes	Yes	Yes	Yes	No
Maestro AR	No	No	No	No	No
Tube-3 Module	Yes	Yes	Yes	Yes	Yes
Xperience Team Trainer	Yes	Yes	No	Yes	No
Robotic Surgery Simulator (RoSS)	Yes	Yes	No	No	No
SimSurgery Educational Platform (SEP) Robot simulator	Yes	Yes	Yes	No	No
ProMIS	Yes	Yes	Yes	No	No
RobotiX Mentor™	Yes	Yes	Yes	No	No

18.2.2.2 Box Trainer

The box trainer is a physical simulation of the surgical scenario of laparoscopic or robotic surgery. It uses a camera, a monitor, and laparoscopic trocars. Inside the box, the use of inanimate and synthetic models allows the trainee to develop basic or advanced laparoscopic skills such as visuospatial perception or suturing. Advantages of box trainers are low price, great flexibility, and availability, as well as being portable allowing the use at home [52]. On the other hand, the anatomical fidelity is low, and the correct representability of tissue texture is difficult to achieve. Several studies have highlighted its benefits, comparing the use of traditional training alone versus traditional training plus structured training on box trainers with significantly higher improvement in surgical skills [53, 54].

18.2.3 Advanced Dry- and Wet-Laboratory Models

Animal and human models represent the steps further for training basic robotic skills. The most frequently used animal models are the euthanized chicken, the canine, and the porcine. The human models can be used as embalmed body parts or cadavers, which can be fresh, fresh-frozen, soft-fix Thiel embalmed, and formalin-fixed [55].

18.2.3.1 Chicken Model

The chicken model is mainly used as a training tool for pyeloplasty and urethrovesical anastomosis (UVA) [20, 56–59]. The euthanized chicken model was validated as a good laparoscopic UVA training tool [59–61]. Specifically, Yang et al. [20] and

Laguna et al. [62] provided construct and content validity for this model by demonstrating its ability to reliably differentiate performance levels between experienced and novice surgeons. After assessing its construct validity, this model was implemented in the evaluation of urology resident's competency and performance levels in laparoscopic or robotic skills [20]. Moreover, it was largely used in all RARP training curricula to develop expertise in UVA anastomosis, by providing a simulation of the posterior fascial reconstruction (Rocco stitch) [58]. Of note, the role of the chicken model for urethrovesical anastomosis has been recently reviewed by Puliatti et al. [63] who developed quantitative metrics in order to objectively assess the performances on this model (Figs. 18.1 and 18.2). After achieving consensus through a Delphi panel on these metrics, this model was subsequently validated by prospectively assessing the performances of experienced and novice surgeons [64]. These validation steps represented the basis for the full implementation of a PBP-based pathway for UVA. Subsequently, the efficacy of PBP in this context has been prospectively assessed in a recent randomized trial comparing performances of novice surgeons from different surgical specialties in practicing a UVA in a chicken

Fig. 18.1 Examples of the chicken anastomotic model

			Suturing operative errors												Knotting operative errors				
	CMP		Conflict of instructions	Missed grasp	Instrument not assisting	Tear or damage tissue:	Suture damage	Incorrect needle grasp	Excessive manipulation	Incorrect tip grasp	Incorrect bite	Incomplete or repeated bite	Incorrect suture bite	Needle out of view	Missed loop	Tail looped	Loose knot	Missed double overhand knot	Failure to alternate the direction of the last 2 throws
Anastomosis errors		Posterior wall																	
	FTP																		
		Left lateral wall																	
	FTP																		
		Right lateral wall																	
	FTP																		
		Anterior wall																	
	FTP																		
		Knotting																	
	FTP																		
			No		Yes														
Critical errors		Anastomosis leakage					Repaired		FTP										
							Not repaired												
		Broken needle or suture					Repaired		FTP										
							Not repaired												
		Catheter fixation during anastomosis					Repaired		FTP										
							Not repaired												

Automatic fail: Time limit: 40 minutes not including the preparation

Fig. 18.2 Scoresheet of the chicken anastomotic model

model. Surgeons were randomized to PBP versus classical training pathways and those trained through the PBP pathways demonstrated lower rates of errors compared to the standard training group [64].

As a training model of the pyeloplasty technique, Ramachandran et al. [56] and Ooi et al. [65] were able to show that training on a pyeloplasty chicken model shortens the learning curve, improve the trainee's confidence, and reduces operative time. Besides its high resemblance to the structure and characteristics of the human pelvis, urethral stump, and bladder, all the materials involved are inexpensive and easily obtained, which makes it an effective convenient training model [57].

18.2.3.2 Canine Model

The majority of the reviewed literature analyzed the role of canine models in preclinical tests of new robotic instruments, as well as in studies assessing the feasibility of new procedures and new robotic surgical approaches [66]. The canine model can be used to train minimally invasive prostate surgery due to the similarity between canine and human prostate anatomy [67]. For instance, canine model training has been fully introduced within the training curriculum in urology [30]. Of note, the similarity of canine prostate anatomy with human prostate anatomy allows to realisticly replicate a real robot-assisted radical prostatectomy with preservation of the neurovascular bundles. However, its use is legally banned or restricted in some countries and there are no studies objectively showing its validity as a training model, which still represents an unmet need.

18.2.3.3 Porcine Model

This model is commonly used to teach surgical skills in gastrointestinal, gynecological, cardiovascular, thoracic, and urological specialties. Its versatility allows training surgeons with different levels of surgical education background, from medical students to experienced urological surgeons [68]. It is used to train single steps of a specific procedures, or to perform full procedures and, in countries where it is illegal to use this porcine model, one should use the canine model. The porcine model represents the first model of choice in surgical training [69].

Several studies have provided evidence supporting its utility in improving surgical skills of trainees. Jiang et al. [57] showed that this model was more effective and realistic than the chicken model for UVA laparoscopic training, Boon et al. [70] proved the construct validity for laparoscopic UVA using a porcine intestine model, and Sabbagh et al. [71] demonstrated that the transferability of laparoscopic UVA skills to a high-fidelity animal model was greater when the training of UVA was directly performed on the animal model as opposed to practicing the basic laparoscopic suturing skills on a foam pad. In a study by Passerotti et al. [72], the authors established the concurrent validity of a pyeloplasty porcine model and compared the quality of the suture anastomosis of the ureteropelvic junction using robot-assisted laparoscopic surgery, freehand laparoscopy, and open surgery. The authors demonstrated that robotic surgery had a shorter learning curve and that the quality of the anastomosis was better when using the robotic platform.

The porcine model allows the trainee to complete full robotic procedures by replicating the same steps performed in human cases, allowing a safe transition from the laboratory to clinical practice and from open to robotic approaches [73]. In this direction, Alemozaffar et al. [74] created a validated realistic and tissue-based simulator from male porcine genitourinary tract to sequentially practice key steps of robot-assisted radical prostatectomy (RARP). In the highly complex field of renal transplantation, Tiong et al. developed a procedure-specific simulation porcine model to train robotic intracorporeal vascular anastomosis [75]. They described the requirements and steps developed for the technique of robotic-assisted renal autotransplantation and evaluated the vascular anastomosis patency, demonstrating adequate face, content, and construct validity of the model, confirming that it can be useful to train steps of robotic intracorporeal vascular anastomosis and can potentially facilitate a confident transition to perform human transplant surgery. A robotic sacro-colpopexy porcine training model was developed by Kasabwala et al. [73] using the da Vinci Xi and Si robotic systems. The results showed an improvement in the economy of motion, tissue handling ability, suturing efficiency, and overall performance of the trainees. Based on this evidence, the authors planned to incorporate some of the aspects of the model into their clinical practice, and recommended it as a necessary training tool for this procedure.

18.2.3.4 Human Cadaveric Model

The human cadaveric model is considered the gold standard for anatomical and surgical training of individual procedures, but its use is highly limited by its availability and cost. It provides ultra-high-fidelity representation of the surgical anatomy in vivo, authentic tissue handling and allows to understand the complex three-dimensional anatomical relationships, which are difficult to appreciate in textbooks and very difficult to replicate in synthetic models [76–78]. The main drawback of this model is the absence of bleeding.

Cadaveric models are frequently used by trainees in advanced training facilities to practice a complete surgical procedure in a high-quality environment, with adequate equipment and psychological fidelity. It was shown that these advantages enable rapid acquisition of basic surgical skills and achieve competence in a setting outside the operatory room [79]. Human cadavers are considered the best models for training robot-assisted surgical procedures, and their restricted availability can be improved through a coordinated use for multiple teaching sessions across different specialties [80]. Notably, several studies reported very high learner satisfaction with the cadaveric model. The use of conventional non-perfused cadaveric material has the drawback of no bleeding risk and thus the simulation fidelity is limited for teaching procedures where bleeding is a potential major consequence. This is the reason why several studies underlined the utility of live cadaveric reconstitution in overcoming criticisms related to conventional non-perfused cadaveric material. In the last few years, there has been increased availability of cadaveric training courses for surgical trainees, although these models are not commonly used during residency training mainly, due to time, cost, and availability constraints [80, 81]. Bertolo et al. [82] demonstrated that robotic training with human cadavers is highly accepted by residents and their supervisors. They reported an immediate improvement in resident performance after a one-day course and considered that training on human cadavers is superior to virtual reality simulators and to porcine cadaver models. A study by Sharma et al. [83] demonstrated significant improvements in self-reported operative confidence and competence, as assessed by oral examination.

18.2.4 Implementation of Basic Skills Modules Within Robotic Training Curricula

From a clinical point of view, surgical training programs have to accommodate the innovations of robot-assisted surgery to guarantee the same clinical outcomes among different centers. This added complexity underlines the fundamental need to design a standardized and validated robotic training curriculum, including adequate training in basic surgical skills. Among these, some curricula are industry driven short training sessions, which lack any formal assessment of proficiency, whereas others are all-inclusive fellowship-style courses that take months to complete (Table 18.2) [30, 84–86, 88–90, 92, 93, 95, 97–105]. In the following paragraphs, we will describe the validated robotic training curricula that fully implement the basic skills tasks modules.

18.2.4.1 Fundamental Skills of Robotic Surgery (FSRS)

The Fundamental Skills of Robotic Surgery (FSRS) training curriculum is a validated, structured, simulation-based training program that was created by the Roswell Cancer Institute in Buffalo, USA. The curriculum consists of 4 modules (orientation, motor skills, basic and intermediate surgical skills) with a series of 16 tasks, with each task containing 3 levels of difficulty and an evaluation phase. The curriculum is performed on the validated RoSS simulator, which automatically records and saves performance metrics of trainees. The tasks were specifically created by a group of expert robotic surgeons with the integration of previously validated tasks from the Fundamentals of Laparoscopic Surgery curriculum [85, 106].

In the validation study of the FSRS, 53 participants without any previous robotic surgical experience were included, whose performance was assessed by three tasks that had to be performed three times each on the da Vinci Surgical System: ball placement, suture pass, and fourth arm manipulation. The participants were randomized into two groups: an experimental group and a control

Table 18.2 Summary of the available Robotic training curricula

Robotic Surgery Training Curricula								
Name	Study	Year	Dry lab/ Simulation	Wet lab	Modular training	Real-Life surgery	Validation	Specialty
Fundamentals of robotic surgery (FRS)	Smith R, et al. [84]	2014	Yes	No	Yes	No	NOT VALIDATED	Multi-specialty
Fundamental skills of robotic surgery (FSRS)	Stegemann AP, et al. [85]	2013	Yes	No	No	No	VALIDATED	Multi-specialty
Roswell Park Cancer Institute Robot Assisted Surgical Training (RAST) program	Attalla K, et al. [86]	2013	Yes	Yes	Yes	No	NOT VALIDATED, but uses FSRS	Multidisciplinary
ERUS robotic surgery training curriculum	Volpe, et al. [30]	2014	Yes	Yes	Yes	Yes	VALIDATED	Urology
ERUS robotic surgery training curriculum for partial nephrectomy	Larcher, et al. [107]	2020	Yes	Yes	Yes	Yes	VALIDATED	Urology
Proficiency-based robotic curriculum	Dulan G, et al. [87]	2012	Yes	No	No	No	VALIDATED	Multidisciplinary
University of Toronto Basic skills training curriculum (BSTC)	Foell K, et al. [88]	2013	Yes	No	No	No	VALIDATED	Multidisciplinary
Society of European Robotic Gynaecological Surgery (SERGS) curriculum	Rusch P, et al. [89]	2018	Yes	Yes	Yes	Yes	VALIDATED	Gynecology
"Western Protocol" Cardiac Surgery Virtual reality curriculum	Valdis M, et al. [90]	2015	Yes	No	No	No	VALIDATED	Cardiac surgery
Fundamentals of robotic surgery: Orlando group	Macgregor JM, et al. [91]	2012	Yes	No	No	No	NOT VALIDATED	Multidisciplinary

(continued)

Table 18.2 (continued)

Robotic Surgery Training Curricula								
Name	Study	Year	Dry lab/ Simulation	Wet lab	Modular training	Real-Life surgery	Validation	Specialty
Association of Program Directors for Colon and Rectal Surgery (APDCRS) Robotic Colorectal Surgery Training Program	Not published [92]	2017	Yes	No	No	Yes	NOT VALIDATED	Colorectal surgery
East Carolina University (ECU) robotic surgery training program	Chitwood WR, et al. [93]	2001	Yes	Yes	No	No	NOT VALIDATED	Mitral valve repair, cholecystectomy, Nissen fundoplication
Society of American Gastrointestinal and Endoscopic Surgeons (SAGES) Robotic Surgery Curriculum	Hanly EJ, et al. [94]	2005	Yes	No	No	No	NOT VALIDATED	General surgery
University of Pittsburgh Medical Center (UPMC) Center for advanced robotics training (CART) Robotic Head & Neck surgery program	Not published [95]	2015	Yes	Yes	No	No	NOT VALIDATED	Head & Neck surgery
University of Pittsburgh Medical Center (UPMC) Center for advanced robotics training (CART) thoracic surgery robotics training program	Not published [95]	2015	Yes	Yes	No	No	NOT VALIDATED	Thoracic surgery
University of Pittsburgh Medical Center (UPMC) Center for advanced robotics training (CART) Surgical oncology Robotics Training program	Not published [95]	215	Yes	Yes	No	No	NOT VALIDATED	General surgery and hepatopancreaticobiliary surgery
British Association of Urological Surgeons (BAUS) Robotic surgery curriculum	Not published [96]	2015	Yes	Yes	Yes	Yes	NOT VALIDATED	Urology

University of Alabama at Birmingham (UAB) Robotic Surgery Curriculum	Not published [97]	NA	Yes	No	Yes	Yes	NOT VALIDATED	Gynecology
Samaritan Hospital General and Colorectal Surgery group Robotic Surgical Training program	Madureira FAV., et al. [98]	2017	Yes	Yes	Yes	Yes	NOT VALIDATED	General surgery, Urology
Texas Association of Surgical Skills Laboratories (TASSL) Training collaborative	Lyons C, et al. [99]	2013	Yes	No	No	No	NOT VALIDATED	Multidisciplinary
Robotic Training Network Curriculum	Not published [100]	NA	Yes	No	Yes	Yes	NOT VALIDATED	Gynecology, General surgery
Fellowship of International College of Robotic Surgeons (FICRS)	Not published [101]	NA	Yes	No	No	Yes	NOT VALIDATED	Multidisciplinary
Transoral Robotic Surgery Curriculum (TORS) Training curriculum	White J, et al. [102]	2018	Yes	Yes	No	No	NOT VALIDATED	Otorhinolaryngology
Emory University School of Medicine Robotic Surgery Training Curriculum:	Not published [103]	NA	Yes	No	No	Yes	NOT VALIDATED	General Surgery

group. Participants of both groups received a didactic session to introduce the da Vinci surgical system, led by an experienced operator. Participants included in the experimental group completed the FSRS training curriculum once in 3 to 4 sessions before completing the three tasks, while participants of the control group had to complete the tasks without completing the FSRS curriculum. Finally, after completing the three tasks, the participants included in the control group were offered to complete the FSRS curriculum and redo the three tasks afterwards as a crossover group.

The participants' performance on the three tasks was evaluated by video assessment by two trained, blinded, and independent reviewers. Assessment parameters included time to complete the tasks, the number of camera and clutch movements, number of collisions, number of drops and number of movements of instruments outside of the field of view. These assessment parameters were scored for each of the three takes of each task and mean values were used for comparison of the performance of the different study groups. Participants in the experimental group demonstrated significantly fewer drops and moved their instruments outside the view of the camera significantly less often than in the control group. When comparing the results of the control group and crossover group participants, there was a significant improvement in time to completion and a significant decrease in the number of errors with significantly fewer drops and movements of instruments outside of the camera's view. Therefore, Stegemann et al. [85] demonstrated that the FSRS curriculum is a valid and feasible training curriculum that can improve trainees' basic robotic surgical skills.

In 2014, the construct validity of the FSRS curriculum was demonstrated by Raza et al. [108] Sixty-one surgeons of variable surgical experience (49 novices and 12 experts) were evaluated when performing 4 tasks (ball placement, coordinated tool control, fourth arm control, and needle handling and exchange), which were selected on expert consensus and represented the core of the 3 modules of the FSRS curriculum. The performance of participants was assessed by the use of the built-in software in the RoSS, which evaluated 10 metrics in each task. Depending on their surgical experience, participants were able to perform 1 or 3 preliminary levels of each task, before the final evaluation started. Raza et al. [108] demonstrated that the expert participants performed significantly better than the novices at all aspects of the individual tasks, thereby proving the construct validity of the FSRS curriculum. Of note, a recent randomized trial by Satava et al. prospectively demonstrated that a proficiency-based progression FSRS curriculum improved the acquisition of basic surgical skills compared to standard training [109].

The Robot Assisted Surgical Training (RAST) program is a 5 day to three-week training curriculum that was developed at Roswell Park Cancer Institute and consists of the validated FSRS curriculum combined with other forms of hands-on training, including HoST-training and wet-lab training. Attalla et al. [86] showed that RAST had an educational impact on trainees [106].

18.2.4.2 Proficiency-Based Robotic Curriculum

The proficiency-based robotic curriculum is a validated, comprehensive training program created by the University of Texas Southwestern Medical Center. The curriculum consists of 3 curricular components: an online tutorial (by Intuitive Surgical) covering fundamental aspects of robotic surgery, a half-day interactive session, and hands-on practice with 9 inanimate exercises. These exercises were developed by interviewing robotic surgery experts and through observation of live robotic surgery, and aim to train 23 unique robotic skills. The exercises are performed on a standard da Vinci system with a box trainer and show increasing degrees of complexity to facilitate proficiency-based skill acquisition. It takes 2 months to complete the training program and trainees have to self-practice the 9 exercises. All exercises are assessed using an objective scoring system based on the validated FLS approach for time and errors [104].

The content and face validity of the proficiency-based robotic curriculum were demonstrated by Dulan et al. [110] when 12 expert robotic surgeons rated each of the 23 deconstructed skills and performed the 9 exercises. They concluded that all 23 deconstructed skills were highly relevant and that all 9 exercises effectively measured relevant skills [106]. Dulan et al. [87] also demonstrated the construct validity of this curriculum in a group of 8 expert robotic surgeons and four novice trainees (medical students). After watching a video showing error avoidance strategies and the correct method to perform the 9 exercises of the curriculum, the participants completed the 9 exercises themselves. Every task of each participant was scored by a single trained proctor for time and accuracy using modified FLS metrics. Expert surgeons were found to achieve significantly better performance than inexperienced students according to each of the nine task scores [106].

18.2.4.3 Basic Skills Training Curriculum (BSTC)

The basic skills training curriculum (BSTC) is a validated 4-week training program developed by the University of Toronto [88]. Trainees undergo a series of didactic lectures and self-directed online training modules (including Fundamentals of Robotic Surgery) before being introduced to the da Vinci robot. The theoretical module, focusing on the cognitive objectives of the BSTC, includes advantages and disadvantages of robotic technology, analysis of the various robotic systems and its equipment, introduction to the patient cart, surgeon console and vision cart, review of the robot installation principles, placement of trocars, docking, exchange of tools, grafting and resolution of common technical problems, and several practical training sessions. After the theoretical module, a 2-h hands-on robotic training session starts, focusing on the topics dealt within the theoretical module. Thereafter, trainees start exercising basic skills on the dVSS such as endowrist manipulation and camera navigation, instrument clutching, instrument and third-arm functionality, object manipulation, needle guidance, suturing and binding of the nodes, cauterization and dissection. This standard set of exercises is repeated for three individual 1-h sessions on the simulator, organized at weekly intervals. The robotic surgical skills of the trainees are evaluated by the built-in assessment tool of the simulator. A trainee passes the test when at least 80% of success has been achieved. Wet-lab or real-life surgery training is not included in this training curriculum.

Pre- and post-course skills tests have been conducted on two skill exercises standardized with inanimate models: ring transfer and needle passage. Studies have demonstrated improvement of robotic surgical skills among trainees, regardless of specialty, previous robotic experience, or level of training [88, 106].

18.2.4.4 "Western Protocol" Cardiac Surgery Virtual Reality Curriculum

In this virtual reality curriculum, participants train different robotic surgical skills exercises on the dVSS that are needed in cardiac surgery, more specifically in the harvesting of the internal thoracic artery and in mitral valve annuloplasty. The training protocol consists of 9 exercises that were selected according to the robotic skills needed for these two surgical procedures, which were defined by two expert robotic cardiac surgeons.

For the validation study of this curriculum, Valdis et al. [90] recruited 20 surgeons with little experience with the da Vinci console or with robotic simulators. The study included a video of the interventions to highlight the basic operative techniques and the relevant anatomy. The training program includes an initial evaluation of a surgical procedure on a porcine chest wall with the aim of collecting 10 cm of the internal thoracic artery. Subsequently, the trainees had to perform a suture on a pig cardiac model of the mitral valve, completing the first 3 sutures of an annuloplasty valve. Each activity was performed only once by each student and was timed and evaluated using the time criteria of the Laparoscopic Fundamentals program.

Of the 20 participants in the study, half were able to practice on the simulator several times (up to 80 times to reach the level of competence established by experts). The other half did not receive any additional training (control group). After the training period, the trainees were compared again on the robotic procedure on the animal model. Intraoperative surgical skills were assessed by the Global Evaluative Assessment of Robotic Skills (GEARS) [90]. Trainees randomized to the VR group were faster than the control group for both surgical procedures and scored significantly higher with the intraoperative scoring tool. Furthermore, trainees included in the VR group achieved a proficiency level similar to the experts for both time-based scores and the intraoperative assessment, whereas the control group was not able to meet this level of proficiency for any of the primary outcomes. Hereby, Valdis et al. [90] proved that the Western Protocol Cardiac VR Curriculum significantly improves the efficiency and quality of learning in robotic cardiac surgery.

18.2.4.5 Other Specialty-Specific Robotic Training Curricula Including Basic Skills Modules

The European Association of Urology Robotic (ERUS) training curriculum is a six-month comprehensive training course which was developed based on an expert panel discussion with the RARP as index procedure [30]. After undergoing a specifically developed e-learning module, trainees observe and assist during live surgery for up to 3 weeks. This is followed by an intensive week of simulation-based training, including VR simulation (using the dVSS), dry- and wet-lab training platforms. The technical robotic skills included are EndoWrist manipulation, camera movement and clutching, use of energy and dissection, and needle driving. Improvement of technical skills is assessed by comparing the scores at baseline and on final assessment using the inbuilt validated assessment metrics on the dVSS. After the basic skills simulations, trainees move on to the fellowship stage, which consists of a supervised modular training program in robot-assisted radical prostatectomy with proficiency-based, progressive training of surgical steps with increasing complexity.

Recently, a novel robotic training curriculum for robot-assisted partial nephrectomy (RAPN) was developed and validated [107]. Similar to the RARP curriculum course, this RAPN-specific pathway guides the trainee from theoretical knowledge to preclinical learning, passing through VR simulators, dry- and wet-laboratory training, up to clinical-based modules practice. After the initial e-learning phase, the RAPN course starts with an intensive week of preclinical simulation-based training that closely replicates that of the RARP curriculum course. Subsequently, the course proceeds with a clinical modular training that is based on the partition of a complete RAPN case into 10 fundamental steps, in order to divide the procedure into replicable modules to be learned.

Similarly, the Society of European Robotic Gynaecological Surgery (SERGS) curriculum is a fellowship-styled, validated tri-modular training curriculum that was designed after the ERUS training curriculum [30, 89]. The SERGS curriculum uses radical hysterectomy and pelvic lymphadenectomy as index procedures. The curriculum starts with a didactic introduction at the home education center. It consists of 2 days of e-learning and 1 month of assistance in robot-assisted gynecological procedures. E-learning is evaluated by online test modules. In this first module, trainees are encouraged to perform virtual reality exercises. After completion of the evaluation tests, the second module starts and consists of a 1-week hands-on procedural training at a European education center for robotic surgery. This includes half a day of theoretical system training, followed by 3 to 4 days of both dry-lab training on the dVSS and wet-lab training on live anesthetized porcine and cadaveric models. Trainees perform hysterectomies, adnexectomies, pelvic and para-aortic lymphadenectomies under the supervision of an expert robotic surgeon. The progress of robotic surgical skills for each individual trainee is evaluated by comparing the overall score on a dVSS virtual training test at the beginning and end of the week. At the end of the training, the performance is assessed by Non-Technical Skills for

Surgeons (NOTSS) for modular training and by GEARS and Objective Structured Assessment of Technical Skills (OSATS) for procedural training. Finally, trainees move on to the last module, which focuses on in-house training with supervised real-life surgery.

18.3 Conclusion

The current chapter provides an overview of the important role played by dry and, especially, wet laboratory models in robotic surgical training. A wide range of training models are available, ranging from VR simulators to human cadaveric models, and its versatility allows the performance of full surgical procedures. Human cadavers are the most realistic, being considered the "gold standard," but their high cost and reduced availability limits their practical use. Thus, porcine and canine models, due to their natural tissue properties, rapidly became important for the acquisition of advanced surgical skills such as dissection, suturing, and use of energy sources, which are all required in real clinical scenarios of robotic-assisted procedures [111]. However, despite these advantages, these models face problems related to licensing and ethical issues. Therefore, VR simulators and box-trainers, given their high accessibility and low cost, are still the most frequently available models for practicing basic robotic skills. The implementation of these models is becoming an integral part of the training of console surgeons, particularly when they are integrated into a structured curriculum. Through this approach, it is possible to improve technical and non-technical skills, prevent the patients from being used as training models, and consequently improve patient safety.

The currently validated basic training models can be used by healthcare organizations to provide supplementary training sessions for trainee surgeons, but further research should be conducted to validate new simulated environments, determining which ones have greater efficacy, assessing their cost-effectiveness and the transferability of skills learnt. In conclusion, VR simulators, dry- and wet-laboratory models combined with the novel methodology of training will be fundamental in providing future surgeons with the necessary skills and knowledge required to start their clinical practice in a safe environment with excellent outcomes [9, 112].

Key Points

- Virtual reality simulators and box trainers are the optimal starting points for practicing basic robotic surgical tasks since they have been repeatedly validated as basic training tools.
- The chicken model has been developed and validated as a training model for pyeloplasty and urethrovesical anastomosis, it is inexpensive and easily available.
- The canine model has been used to test several new technologies, but it has not been validated as a training tool.

- The porcine model is mainly used for training different surgical steps or full procedures (e.g., urethrovesical anastomosis, pyeloplasty, radical prostatectomy, or sacrocolpopexy).
- The human cadaveric model is considered the gold standard for robotic surgical training and surgical technique feasibility; however, its limited availability, high cost, and lack of bleeding are drawbacks.
- The full implementation of these dry- and wet-laboratory models is an integral part of the console surgeon's training, particularly when they are integrated into a structured robotic surgery curriculum.

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Chapter 19
Procedural Robotic Skills Training

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19.1 Introduction

19.1.1 Procedural Skills Training

Procedures are a fundamental part of daily health care. Procedural skills are usually acquired during residency. But due to the constant development of new technologies, and especially the introduction of minimally invasive surgery, the number and types of skills that residents need to acquire have increased dramatically. Residents in urology should be able to perform over 170 procedures with varying degrees of complexity at the end of their residency. For the past two centuries, the most popular training

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paradigm was the Halstedian “see one, do one, teach one,” [1] which consisted of observing, performing, and then teaching others to perform procedures as learning method. With the introduction of new regulations limiting working hours, increasing bureaucracy and concerns about trainees operating on patients [2], training has undergone a paradigm shift that has impacted residents’ knowledge of procedural skills. Patient’s safety aside, Halsted’s approach has been shown to be flawed as learners need more than observation to be able to perform a certain procedure and teach it to others. Historically, much of the experience of surgeons has developed after entering medical practice and performing procedures on live patients. Despite having completed training, physicians may still be at the start of their learning curve for certain techniques and procedures when starting their own practice [3]. This substantially increases the risk to damage patient’s health and increases overall morbidity. This pattern has often been observed in experienced surgeons who are learning new skills or new techniques. Several studies on complications after minimally invasive procedures support these data, and have shown that the majority of surgeons’ complications occur in the early part of their learning curve [4]. Procedural skills learning should focus on providing an optimal setting in which skills can be built and developed with a specific, structured, and safe process. Furthermore, the ideal training process should evaluate whether a trainee has reached a benchmarked proficiency level of performance before moving on to the next step. Today, courses for procedural learning typically consist of lectures on indications and techniques, followed by a hands-on skills lab, without structured teaching methodology and lacking end-of-course assessment. Learning a new procedure should be based on validated educational techniques, such as proficiency-based progression training, and include a cognitive understanding of the procedure itself with appropriate clinical application. In addition, trainees should be aware of what they should and, more importantly, what they should not do when performing the procedure [5]. The skills involved should then be learned and practiced until the quantitatively defined proficiency benchmark is demonstrated in the laboratory setting or through simulation training. The use of wet and dry lab simulation allows trainees to develop skills in a safe environment and increases patient safety [6]. Only when proficiency is demonstrated against a previously established benchmark, trainees should proceed to perform the procedure in a real-life setting. The medical community who provides this surgical procedural skills training should develop and validate evidence-based curricula that are capable of training the required skills for full surgical procedures. This is done by moving away from exposure-based assessment and move on to proficiency-based assessment. Without this paradigm shift, it is unlikely that a consistent improvement of the surgical performance level and quality of skills will be achieved.

19.1.2 Current Role of Procedural Skills Training in Robotic Surgery

Over the last 20 years, the role of robotic surgery has increased due to the advantages that minimally invasive surgery (MIS) and robotic surgery bring. Urologists have been pioneers in adopting robotic surgery as standard of care for several pathologies, such as prostate cancer and nephron-sparing kidney surgery. Nonetheless, the introduction of these new technologies and the shift to the so-called key-hole surgery has been accompanied by a significant increase in adverse events related to MIS procedures [7].

In the 1990s, a succession of adverse medical events [8, 9] led to several lawsuits [10, 11] against one of the principal manufacturers of surgical robots, drawing the attention of the general public and the authorities [12] to clinical training. Despite this increased scrutiny, a recent paper shows that 33% of surgical residents in the USA are not ready to perform core procedures independently at the time of residency completion [13].

Still, no guidelines on training in robotic surgery nor structured training path for this surgical technique are available. To reduce the exposure of patients to possible risks, the presence of structured, standardized, validated, and effective curricula is necessary to produce accredited and certified robotic surgeons. A series of validated and unvalidated robotic curricula have been developed for robotic skill training [14], either mainly based on simulation (FSRS) (Fundamental Skills of Robotic Surgery) [15], proficiency-based robotic curriculum [16], BSTC (basic skill training curriculum) [4] or structured curricula ERUS training curriculum [17], SERGS curriculum [18], ERUS curriculum for partial nephrectomy [19]. The validated curricula demonstrate that a structured training pathway improves surgical performance. However, all these curricula lack objective assessment of trainees' performance. Trainees, regardless of their previous expertise, should demonstrate a quantitatively defined performance standard before progressing to the next step within the curriculum, and certainly before they use the device on real patients. Proficiency-based progression (PBP) training has proven that trainees who completed courses that employed this methodology, outperform trainees from traditionale programs in clinical settings [20]. PBP uses metrics derived from expert performance and, after validation, these metrics are used to set benchmarks which trainees must attain before progressing [6]. This approach assures the quality and skill level of trainees at the end of their training path and it helps to standardize performance levels when using surgical robots [21].

19.2 Acquisition, Maintenance, and Loss of Surgical Skills

19.2.1 Factors Affecting the Duration of Training

The development of procedural skills requires theoretical and practical comprehension of the skill itself, as well as the physical ability to execute the required movements [22]. The training needed to obtain and maintain these skills increases proportionally with the difficulty of the procedure. Moreover, learning a motor skill is a developing process that consists of constant refinement and improvement. According to Fitts and Posner [23], learning a new skill is a three-phase process:

- Cognitive phase (the learner develops an understanding of the sequence of movement required);
- Associative phase (the learner practices until an efficient performance emerges and single steps are combined into smoothly executed actions; the learner begins to perform more than one task at a time);
- Autonomous phase (through practice actions become automatic, unconscious, and instinctive).

A learning curve exists for all procedures that require the execution of a technical motor skill. Progressing along the learning curve depends on several factors, including the technical difficulty of the skill, the availability of training tools, and the training methods used. Moreover, the visuospatial, perceptual, and psychomotor talents of trainees play a significant role. Training exercises and operational experience are the primary means of moving up the learning curve. The better training tools mimic a specific task or simulate real-world context, the more effective they are in helping the trainee acquire skills. Of note, during each stage of learning, an initial performance improvement is followed by a plateau, with very little progression until the learner moves up to the next stage. Some trainees will progress up the learning curve more efficiently, while others will take longer [24]. A slow acquisition of component skills will result in a protracted learning curve. Practice and repetition do not ensure success if the training exercises do not provide accurate real-world experience. Repeated practice alone may cause the student to plateau rather than move vertically along the learning curve. A major issue related to the elongation of the learning curve, is the deterioration of acquired skills over time if they are not repeatedly practiced and/or applied. A student may initially make good progress, but skill deterioration may prevent the achievement of proficiency. Skills related to minimally invasive surgery have been shown to be optimally acquired when trained with an interval/distributed practice schedule. Once acquired, skills appear to be retained and consolidated after one week. However, they significantly deteriorate on all objectively assessed parameters two weeks after completion of training [25]. One of the advantages of a proficiency-based progression training program is that participants practice the skill in the most efficient way, climbing steadily up the learning curve and assuring the retention of technical skills. Moreover, a PBP based curriculum does not require trainees to redo the entire course after a certain period of time. All they have to do is demonstrate proficiency since skills once acquired are easily relearned through a process known as spontaneous recovery. This feature contributes to reducing the length of the learning curve.

19.2.2 Attentional Capacity

Attention refers to the ability to concentrate cognitive resources on performing a certain task, such as observing or listening. Human beings possess a limited amount of attentional capacity. In other words, we can only pay attention to a certain amount of information at any given time. During the initial phases of acquiring a new surgical skill, trainees must use almost all their attentional resources to monitor their hands, trying to coordinate movements while giving attention to their surroundings while trying to recall the steps of the surgical task they are performing. In the event of an unexpected intraoperative complication, they have not enough attentional resources available to even notice the complication itself. As long as trainees progress along the learning curve, the number of automated skills increases, and so "frees" attentional capacity. This happens because basic skills such as simple hand–eye coordination will eventually automate, leaving more attentional resources available. Two main factors impacting on the use of attentional resources are the skill level of the surgeon and his/her experience. Skill level is directly connected with the trainees' innate abilities. The more innate visio-spatial, perceptual, and psychomotor ability they have, the faster they will be able to automate and reduce attentional resources needed to monitor the basic aspects of a skill. Experience is linked to the number of procedures performed by a learner. One of the major advantages of simulation is that it allows trainees to perform procedures until they have reached proficiency and during this proces, frees an adequate amount of attentional capacity in a risk-free environment [26].

19.2.3 Automating Skills

As previously outlined, learning a new skill involves three phases: cognitive, associative, and autonomous. During the cognitive phase, trainees focus on the sequence of events that constitute the building blocks of the full task [27]. In progressing to the associative phase, trainees practice the single steps of the procedure, dropping ineffective features, and smoothing the transition from one step to another. During this phase, the student "knows the procedure" and increases the number of automated skills. The autonomous phase is reached when the trainee "knows how to do the procedure." The skills are perfected through practice until the planned activities are performed automatically. Phases 1 and 2 rely on a considerable amount of cognitive resources, while in phase 3 learners can complete the task even in the presence of distracting factors. A known disadvantage of phase 3 is that the declarative knowledge of skills is often lost. Another issue associated with skill automation is the acquisition of bad habits during training, especially in the case of poorly designed or poorly monitored simulations. The use of validated PBP based curricula reduces the risk of developing bad automated habits and helps trainees to move smoothly through the three phases of learning. Follow-up practice and training are necessary to maintain proficiency in the acquired automated skills. At 12 months from training, after developing automated skills, surgeons without further exposure were 7 times more likely to have a complication when compared with those who engaged in additional instruction [25].

19.2.4 Simulation as a Tool

The use of simulation in surgical skill development was introduced two decades ago by Satava [28]. The introduction of MIST VR revolutionized surgical training, making it efficient and cost effective. The use of virtual reality (VR) simulators has already been validated. Furthermore, it has been shown how surgical skills acquired during simulation are effectively transferred to the operating room [6, 28, 29]. With the development of new forms of simulation and new simulators, skill emulation has become increasingly effective. As robotic technology keeps spreading, new simulators, primarily based on software integrated into consoles, have been developed and implemented. Some simulators have become an integral part of curricula developed to teach basic device skills, allowing the acquisition of skills such as robotic arm movement, effective use of the camera, use of dissection and suturing. One of the greatest limitations of current simulators that are installed in robotic platforms, is the lack of validated metrics. Specifically, the metrics currently used do not allow the simulator to discriminate between different levels of technical expertise. Additionally, evaluation systems implemented in most simulators use global rating scales (GRS) along with analysis of time to task completion, motion analysis, and instrument collision to evaluate the student. These metrics cannot be used as surrogates to evaluate trainees' proficiency, as they poorly reflect the students' ability to perform a specific surgical task. The only metric which is currently used in surgical simulators, and that has been recognized as part of an effective proficiency assessment tool, is the attention to avoiding instrument collision. This avoiding of instrument collision is until now the best available discriminator between novice and experienced user. Future perspectives are the creation of virtual individual curricula based on proficiency-based progression, in which, thanks to the integration of artificial intelligence systems, simulators will be able to recognize errors based on metrics that are validated by experts. Besides the use of VR simulators, several dry- and wet-lab models have been developed. A recent review evaluating the use of an affordable, homemade system for skill training has proven that several basic skills and urological procedures can be trained in a cost-effective way [30]. However, these solutions are not suitable for robotic training as they lack standardization and do not use validated metrics to evaluate trainees' performances. Several animal-based models have been used over the years. Recently, the Venezuelan chicken model has seen an increase in popularity for its role in the simulation of basic robotic skills, mainly due to its similarity with real-life experience [20, 31]. Simulation is of the utmost importance in surgical training. Despite its limitations, it has proven to increase surgical proficiency and reduce operative errors, therefore limiting patients' morbidity as well as the costs that are associated with the treatment of complications. However, even though simulation has a tremendous potential in contributing to surgical skill development, we must not forget Dr. Satava's admonition—"It is not the simulator, it is the curriculum." Simulation should be used as a cornerstone in the development of curricula that are able to train novice surgeons up to proficiency and thus produces the experts of tomorrow.

19.3 Metrics and Curriculum Development

19.3.1 Performance Metrics

According to the PBP methodology [5], the entire process of metric development starts with analyzing a certain skill through a detailed task analysis. Task analysis is performed to reach a consensus between experts on the characteristics of the reference procedure. Procedure performance should be guided by manufacturer recommendations on device usage, scientific society guidelines, and results from empirical studies. In the absence of a consensus between the experts on the aforementioned items, practical wisdom should be employed. Task analyses involve a breakdown of the skills steps and identifying the steps necessary to complete the procedure. Each step needs to be operationally defined, specifying the order, duration, and results of the step, rather than just a simple description. The identified units of performance are defined as metric units of task execution, providing a quantitative standard of measurement. These units are used to define and shape the simulations developed to train a task performance. Metrics definitions should be complete, indicating the beginning and endpoints of each step with detailed description in order to score performance reliably. Metrics should define errors for each procedure step. Errors are defined as actions that deviate from optimal practice, while critical errors are unsafe actions which may lead to bad outcomes. Finally, the metric should be scored as a binary outcome ("Yes" or "No"), rather than in a Likert-scale fashion. After their development, metrics must be validated. Metrics are first validated according to content validity. Content validity consists of an evaluation of the contents of metric units by a panel of experts. Once definitions are verified, metrics must undergo construct validation. The aim of metrics is to allow effective differentiation between different levels of performance.

19.3.2 The Role of the "Experts"

According to Dreyfus definition [32], experts are defined as a source of knowledge and information for others regarding a certain procedure; they are characterized by a continuous research for better, improved, performances while working primarily from intuition. Their role in procedural skills training according to PBP methodology is of utmost importance since they are necessary both for metric development, validation and for the establishment of the benchmarked scores to define proficiency. As previously stated, the task analyses and content validity are conducted to reach consensus among experts. A modified Delphi Panel provides an interactive communication platform between researchers and experts to provide feedback and opinions on a certain theme (i.e., the accuracy of the metrics developed for a reference procedure). It is an interactive process in which the desired result is acquired through a series of debates, bringing closer to the desired result as the number of iterations increases. Each cycle should include questioning, deliberation, metric modification, and voting on the appropriateness of each refined metric definition. Each modified Delphi Panel should start with a literature review demonstrating the validity of that training approach for procedural specialties and revising the objectives of the Panel. Each metric unit should be evaluated individually and after each presentation, panel members should vote on whether or not the metric is acceptable. An affirmative vote by a panel member indicates that the metric definition is accurate and acceptable. The ultimate aim of the panel is to reach a consensus among the experts regarding the metrics' definitions. In the event that the panel of experts cannot achieve consensus, the metric definition is revised, and a new vote is conducted on the acceptability of the modified metric. This process should be repeated until consensus is reached.

Another paramount role of the experts is to set the definition of the proficiency level. Proficiency is defined as scoring equally or better than the mean score achieved by the experts when applying the validated metrics to simulation. This does not imply that proficient trainees have the same procedural skills or the surgical ability as experts, rather that they were able to achieve that performance level on two consecutive trials. Reaching proficiency allows trainees to progress to the next skill set or to in vivo practice.

19.3.3 Deliberate vs Repeated Practice

Practice means learning by repetition. However, mindlessly repeating the same action does not guarantee improved performance. Repeated practice, even when unsupervised, may lead to replicating the same mistakes over and over, without learning from them. Furthermore, with simple repetition, no indications of performance quality are provided. Deliberate practice is specifically designed to improve a certain performance. This approach to training relies on detailed metrics for the development of a training program [5]. The procedure characterization must be a valid representation of the actual procedure to be learned, and should be performed by experts. Through metrics, trainees learn precisely what they need to know, what they have to do, and what errors they should avoid. Trainees are given feedback on the errors they made during training in the skills laboratory during simulation. Indeed, deliberate practice training in simulation settings has proven to have the greatest impact on procedure errors [29] and, therefore reducing intraoperative errors [33]. One major advantage of simulation, and particularly virtual reality simulation, is that it allows for repeated deliberate practice on the exact same model. In the operating room, trainee surgeons often experience different scenarios. While this represents the real world, it is not optimal for training, particularly during the early stages of learning. Therefore, virtual reality simulation offers a training platform for skill acquisition rather than for plain repetition. Deliberate practice training differs from traditional repetition because trainees are provided with constant formative feedback on their performance throughout the whole training process [34], increasing effectiveness and efficiency. Without constructive feedback, learning is considerably weakened, even for highly motivated trainees. Through metric-based training, trainees can get precise feedback on what they did wrong. Moreover, trainers' feedback can help them generate new methods or approaches to successfully complete the procedure or task. As the complexity of the procedural skills increases, the risk of not performing the procedure correctly increases as well. To ensure efficient learning, explicit instructions should be given to trainees and individualized supervision should be given, facilitating early identification of performance errors. Since the performance characteristics of advanced procedural skills are usually highly complex, the deliberate practice should focus on reinforcing small steps or approximations toward the final goal rather than simply reinforcing the final response itself. This approach will lead to major retention and reinforcement of performance characteristics increasingly similar to the final goal, while useless or incorrect performances are progressively dropped. Trainees are forced to pay attention to the detail technique of the skills that they are learning rather than aiming for the outcome goal.

What distinguishes an excellent surgeon from a good surgeon is their attention to detail. Formative feedback (particularly feedback on errors) should be given at the end of each performance so that students can learn which aspect was poorly performed and correct it immediately. Summative feedback is valuable but less effective at driving the learning process. It may provide motivation, but formative feedback teaches them what they have to fix, and at what stage of the procedure. Another crucial characteristic for the success of deliberate practice, is the motivation of trainees. Trainees should be aware that acquiring the performance characteristics to a sufficient practice level should not necessarily be a painful process, but that a constant and consistent effort should be made. Deliberate practice applied to sports shows the importance of maximal effort during practice. It has been demonstrated that effortful learning is associated with superior recall and skill maintenance. However, effortful learning must not translate into long and excruciating training sessions. The optimal deliberate practice maintains an equilibrium between effort and recovery and through regular increases in amounts of practice (e.g., >20 min at a time) allows for adaptation and for memory consolidation and has been demonstrated how practice sessions should not exceed 1 h duration. Finally, one major factor impacting on the effect of deliberate practice on skill acquisition is the quality of pre-practical preparation. If the trainees have a lack of knowledge regarding the skill's approach and context, training is less likely to be effective. Moreover, trainees' previous knowledge optimizes recall and performance. Well-configured content sequencing offers an optimal opportunity for information to be learned and remembered by trainees; therefore, thoughtful configuration and organization of learning materials is mandatory.

19.3.4 Proficiency Assessment

The intent of any surgical training program is to enable the trainee to acquire the required skills to perform the designated surgery safely. To accomplish that, performance must be assessed. It is mandatory to verify that mastery of those skill sets can be accurately measured during the trainee's progress. It must also be confirmed that the acquisition of those skills is predictive of the ability to perform a safe and efficient surgical procedure. Being the core building block of any training program based on PBP methodology, proficiency assessment should be performed according to certain standards. First, the accurate task analysis stage of metric development is crucial. Metrics should not only define how skills are performed but must also provide the opportunity for meaningful assessment of the trainee's performance and progress. Benchmark definition is mandatory to objectively define proficiency. In PBP, benchmarks are defined using the mean value of the performance of experts. This approach provides an accurately defined score to proficiency, rather than a vague definition. Proficiency assessment in PBP employs precise definitions of performance and simply requires the reviewer to report whether the specific event occurred or not. This binary approach to the measurement of individual events facilitates reliable scoring of metric-based performance units across a variety of functions during skills training [33, 35, 36]. Other approaches to the measurement of surgical performance, such as GEARS [37], use qualitative descriptions of performance and require the user to rate items on a graduated Likert scale [38]. Likert scales assign a quantitative value to qualitative data and are typically constructed with opinions around a neutral option (i.e., "needle manipulation during suturing was: 1 = imprecise …3 = effective…5 = highly effective"). Considering that they were originally designed to assess a range of attitudes, and because of the major impact of subjectivity, the use of the Likert scales to rate objective performance can hinder procedure scoring, making it difficult to obtain adequate levels of inter-rater reliability (≥80%). The PBP approach has been shown to be more reliable than Likert-scale scoring [39]. Ideally, proficiency assessment should be used as a fundamental step in licensing surgeons to perform robot-assisted surgery, or in general minimally invasive surgery.

19.4 Skills Training

19.4.1 Basic Device Training

Medical devices in clinical settings require their end-users to be trained to make their use safe and effective. The Orsi Consensus Meeting on European Robotic Training (OCERT), the first multispecialty consensus meeting evaluating the opinions of experts from different scientific societies on training in robot-assisted surgery, recently deliberated on the importance of basic device training as a core part of curricula for the accreditation of surgeons to practice robot-assisted surgery [21]. However, not all medical device companies provide trainees with structured and effective basic device training programs. A well-structured training should comprehend a prior mandatory theoretical part, ideally on e-learning platforms allowing an interactive and effective knowledge acquisition, followed by hands-on device training on a simulation environment, supported by constant feedback from trainers. One of the greatest risks associated with the absence of basic device training is not knowing how to properly operate all device components, which can lead to safety risks for the patient. In addition, in the absence of knowledge about the full potential and functionality of a new device, a surgeon may be tempted to directly carry over, without any form of adaptation, the knowledge previously gained from another method or device. This risk is more present in the case of non-novice surgeons; for example, laparoscopic surgeons approaching robotics, in the absence of adequate knowledge about the potential of robotic surgery. They could be tempted not to make use of the degrees of freedom of the robotic instruments, not to correctly use the third arm, or may use wristed robotic instruments the same way as laparoscopic instruments. The program should also train users on key troubleshooting tasks, as well as device care and maintenance. Training should be scaled and "chunked" in order to facilitate information retention and recall. Training should be divided into manageable modules, sometimes over multiple sessions or days.

19.4.2 Basic Skills Training

As previously stated, despite the major advantages for patients' health that comes with robotic surgery, the inadequate preparation of robotic surgeons can result in a higher risk of complications during surgical procedures [7, 40]. The mission of introducing surgeons into the OR only when they have demonstrated that they have reached the pre-set proficiency level in technical skills, is one of the most serious issues in the surgical and educational communities [14]. Regardless of their experience level, surgeons should be well trained in the skills laboratory, before moving on to real patients. Proficiency-based progression (PBP) has proven to be more effective in training surgical skills [33] and in improving clinical outcomes. The acquisition of basic surgical skills is a fundamental step in creating a safe and efficient robotic surgeon. Core basic surgical skills in robotic surgery are suturing, knotting, coagulating, and dissecting [21]. Basic skills training represents a fundamental step to improve manual dexterity and in the acquisition of basic robotic surgical expertise. Several models for the development of basic skills have been proposed, such as dry lab, wet lab, and virtual reality simulation models. The aim of these models is to mimic real-life scenarios and to provide novice surgeons with the opportunity to practice these skills [41]. Despite the increasing availability of training platforms, the lack of a structured curriculum and evaluation of proficiency at the end of the training path, strongly limits their potential role in surgeons' training. A recent study evaluated the use of the "Venezuelan chicken model" for trainees to learn robotic suturing, anastomosis, and knot tying, finding that, with the use of a structured PBP-based training, it can successfully train surgeons on basic skills [31].

19.4.3 Procedure and Advanced Robotic Skills Training

Proficiency based progression (PBP) training provides impartial and validated metrics to track progression and operative skill on a specific task or procedure before the trainees are allowed to start their surgical carreer on patients. The increasing use of robot-assisted technology imposes the necessity to set standardized training paths to optimize patients' outcomes. From a clinical viewpoint, technological innovations that come with robot-assisted surgery should be sustained by developments in surgical training programs in order to guarantee similar clinical outcomes among different centers. With time, it is becoming mandatory to standardize training with defined and validated performance metrics in order to enable a PBP-training program. Indeed, robotic training and education need to be modernized and augmented. However, to date, there is a paucity of validated and structured procedural or advanced skills training. As a first step to achieving this goal, the European Association of Urology (EAU) Robotic Urology Section (ERUS) has designed and established the first structured robotic curriculum focussing on RARP [17] in order to provide novice robotic surgeons with the skills to perform independent full RARP and to improve the outcomes of the patients treated during the learning curve. However, the ERUS curriculum is not based on objectifiable metrics. One of the greatest challenges in implementing PBP in procedure training is that objective and valid metrics must be developed for increasingly complex procedures. In pursuit of this goal, Mottrie et al. recently developed and validated performance metrics for RARP, laying the foundation to implement a simulation based PBP training program for modular advanced robotic skills training [42].

Key Points

- The increasing popularity of minimally invasive surgery has created the urge to train proficient specialists, in order to safeguard patients' safety.
- Simulation is of the utmost importance in developing structured training programs.
- Proficiency-based progression training guarantees an effective training and proficient trainees.
- Basic device and basic skills training are the cornerstone of robotic training and should be mastered before trainees are allowed to move from simulation to operation rooms.
- To date, no validated curricula based on PBP are available.

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Chapter 20
Validated Training Curricula in Robotic Urology

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20.1 Introduction

Robot-assisted procedures have been increasingly adopted over the last two decades because of the advantages of three-dimensional vision, a shorter learning curve, increased dexterity and precision, and better ergonomics for the surgeon [1]. These advantages have led to robotic surgery becoming the prevalent approach of minimally invasive surgery worldwide, with approximately 4500 Da Vinci robotic systems (Intuitive Surgical Inc., Sunnyvale, CA, USA) in action in 2018 [2, 3], with

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robot-assisted radical prostatectomy (RARP) as the most commonly performed robotic procedure worldwide [4]. With respect to this, the implementation of robotic surgery in this field has led to equivalent oncological outcomes compared to open or laparoscopic surgery with the advantage of having superior peri-operative and functional outcomes [5].

However, "*a fool with a tool, is still a fool.*" The rapid increase of robotic systems has not yet been translated into an even greater increase in the training of robotic surgeons. Consequently, a significant proportion of surgeons start using robotics without being adequately trained according to validated training curricula, and therefore expose their patients to unnecessary risks of unfulfilled learning curves [6, 7]. This has resulted in increased adverse events [8].

The phenomenon of inadequate training is not unique to the implementation of robotic surgery, but could be applied to every field in medicine and could result in a significant number of medical errors and preventable complications. In the book "Why Hospitals Should Fly," the author reported mortality comparisons between the aviation and healthcare industries over a 5-year period between 2001 and 2006, with zero deaths on commercial US flights compared to an estimated 250–500,000 deaths from medical errors in the US healthcare system at the same time [9, 10]. Nonetheless, the structure of training in aviation and robotic surgery has many similarities, and both parties control complex technology with their hands, that if managed inappropriately, could result in fatal consequences. This significant difference in outcomes could be explained by the different approaches to training. The increased standardization, with internationally agreed training standards, forms the basis of pilot training in the airline industry. Evaluation and regulation comprised of benchmarked high-stakes tests related to proficiency-based training, result in quality assurance [10, 11] and should also be the way forward in surgical robotic training since we live in an era of outcome-based surgery. The implementation of structured, standardized, and validated curricula in a non-clinical training environment will form the basis of this process [12]. In these times, it is not justifiable anymore, that living patients are being used as training objects.

20.2 Elements of Training Programs in Robotic Surgery

A structured training curriculum should include theoretical training (e-learning, case observation), preclinical simulation-based training (virtual reality simulation, dry and wet lab), clinical modular training, and a final evaluation [13].

20.2.1 E-learning Instruments

E-learning, and, more generally, video training, are essential tools for acquiring theoretical notions and technical skills. In surgical practice, it allows a proctor to guide his trainee using procedure-specific training videos. New e-learning processes are emerging to spread knowledge about a single procedure [14]. New online learning platforms have the ability to incorporate procedure-specific operative metrics to offer novice surgeons a stepwise approach in technical skill acquirement as part of proficiency-based training curriculum [15]. Furthermore, procedure-specific assessment tools could be used to perform a video-based assessment of a surgical performance [16]. Moreover, these e-learning processes are easily accessible and can be quickly updated [17]. Maertens et al. [18] have shown how e-learning can have higher or equal effectiveness compared with both no intervention and non-learning interventions. Angelo et al. also indicated that implementation of an e-curriculum as concept of a proficiency-based progression (PBP) training methodology led to a significantly lower amount of procedural errors [15]. However, the introduction of these new learning processes is far from simple and requires the introduction of new methods of digital learning assessment and a redefinition of educational roles [19]. To date, there are no e-learning platforms in the robotic surgical field that have undergone an adequate and complete validation process.

20.2.2 Preclinical Simulation-Based Training

Virtual reality simulators are already an integral part of most of the curricula in literature [20–22] and have been shown to improve surgical skills in an out-of-hospital setting [12, 23]. The main ones available on the market are: da Vinci Skills Simulator (dVSS) (Intuitive Surgical, Sunnyvale, Santa Clara County, CA, USA), the Robotic Surgical Simulator (RoSS) (Simulated Surgical Systems, Buffalo, NY, USA), SEP robot (SimSurgery, Norway), d-V-Trainer (Mimic Technologies Inc., Seattle, WA, USA), ProMIS (Haptica, Ireland), and RobotiX Mentor (3D Systems, Israel). The most widely used today is the dVSS [24]. However, the d-V-Trainer is considered the most validated [25].

Benchtop simulators are the main tools found inside the dry lab. They are inexpensive, easy to carry, and useful for improving surgical skills. But they are rarely attractive to learners, and are unable to simulate a real surgical setting [23]. They could be used in the simulation phase of robotic docking. Some studies in the literature have established a partial validation of dry lab simulators [26, 27].

Two main simulation models are available in the wet-lab: animals and human cadavers. The animal tissue is of low cost but needs particular facilities for its conservation. Entire deceased animals and living animals are among the best existing simulation models [28]. They allow one to distinguish the consistency of tissues, to replicate the real anatomy and to practice the on-patient operation in a reliable manner. However, this type of training involves very high costs, legal requirements, and availability for single use only [29, 30]. The human cadaveric model is the gold standard for anatomical training; however, it has the same problems as mentioned for the animal model.

During the preclinical simulation-based training, a real-life case observation in a training center by an experienced robotic surgeon is essential as this also includes the circumstances of an operation theater, the associated stress factors, and interhuman relationships.

20.2.3 Clinical Modular Training

It consists of performing supervised surgery in a modular fashion under the expert surgeon's supervision. Progressive, proficiency-based training through surgical steps with increasing levels of complexity is performed. At the end of the clinical training, the trainee should perform a complete procedure that needs to be recorded and evaluated by certified independent examiners in a blind-review process using recognized assessment tools [31].

20.2.4 Full Immersion Simulation and High-Fidelity Operating Room Simulation

The success of the surgical robotic procedure depends not only on the surgeon's technical skills, but also on his/her non-technical skills and the preparation of his/her surgical team [32]. Recognition that, besides technical skills, also cognitive (thinking) and non-technical skills (NTS) will contribute to the development of robotic surgery curricula. To develop these skills in a standardized way, the main methods used are the classroom lessons, the full immersion simulation, and high-fidelity operating room simulation [33, 34].

20.2.5 Tele-Mentoring

Although not very relevant at present, tele-mentoring offers several advantages, making it most likely to play a fundamental role in future training and curricula. The possibility that experts in the field can guide novice surgeons, even when being remotely from each other opens perspectives. Moreover, technological advancement and the introduction of the 5G network could, in the future, even allow proctors to take over the master controls in case of an emergency or trouble. Financial, legal, ethical, economic, and security issues still need to be addressed and solved before being able to integrate this ingredient into the training process adequately [35].

20.3 Critical Issues in the Development of a Robotic Training Program

20.3.1 Adequate Training Time to Perform Safe Surgery

The learning curve is the process during which a novice surgeon gains experience, ability, and skills until reaching a plateau of having optimal operative results. Importantly, the initial phase of the learning curve can be burdened by nonoptimal technical, functional, and oncological results [36, 37]. The duration of this learning curve is procedure dependent and is associated with the level of complexity of the specific task. Taking, for example, the learning curve for robotic-assisted radical prostatectomy (RARP), this was estimated by some authors to be between 12 and 250 procedures based on measurable variables, while others showed a substantial reduction of positive surgical margins (PSMs) after 200 and 1600 procedures [38, 39]. Bravi et al. [34] also showed that previous open surgical experience does not correlate with the risk of PSMs during RARP. Implementation of structured and validated training curricula should aim to overcome the learning curve with its suboptimal results, in a non-clinical training center in order not to expose patients to the inexperience of novice surgeons [40].

Over the last decades, there has been a transition of the duties of surgeons in training, with more emphasis on non-clinical bureaucracy work. Moreover, due to an increased number of surgical procedures to learn during training and due to restricted working hours, fewer surgeons are fully trained and able to operate independently at the end of their training [41]. This might affect the patient's health. Consequently, additional training fellowships to acquire the necessary skills are needed. Validated training curricula with preset proficiency benchmarks should be able to overcome the limited time issues by optimizing the quality of the training [42]. Of note, the foreseen training course should have sufficient length to reach the preset benchmarks and quality standards. For this reason, for example, the initial training period planned for the European Association of Urology Robotic Training Curriculum was 3 months and was then updated to 6 months, to allow all participants a sufficient amount of time to acquire the necessary expertise [43–46].

20.3.2 Cost of Training

The need for equipment, simulators, dual consoles, wet-lab training materials and the use of facilities at recognized training centers makes robotic surgery training extremely expensive compared to open and laparoscopic surgery. It seems correlated with the length of the learning curve, quantifiable between 95,000 and 1,365,000 dollars [13, 47]. Implementation of validated training curricula and the transition of training outside of the hospital will increase the cost of training further. However, this aims to deliver surgeons who have completed their learning curve and therefore should lead to decreased peri-operative complications. Consequently, this could be translated into lower hospital costs [48].

20.4 Available Robotic Surgical Training Curricula

Table 20.1 shows that several training programs are available [53]. However, the majority are characterized by short training sessions that rely exclusively on preclinical simulation-based training (virtual-reality/dry-lab/wet-lab). Conversely,

Table 20.1 Summary of validated training curricula

Validated training curricula	References	Curriculum type
Fundamental skills of robotic surgery (FSRS)	[11]	Simulation-based curriculum
Proficiency-based Robotic curriculum	[49]	Simulation-based curriculum
Basic skills training curriculum (BSTC)	[50]	Simulation-based curriculum
European Association of Urology Robotic Urology Section (ERUS) training curriculum	[44]	Structured curriculum
The ERUS curriculum for robot-assisted partial nephrectomy	[51]	Structured curriculum
The ERUS curriculum for robot-assisted radical cystectomy	[52]	Structured curriculum

only a few are all-inclusive fellowship-style programs that include clinical modular training. Of these curricula, a few have been validated [11, 44, 45, 54].

20.4.1 *Validated Robotic Surgical Training Curricula (Table 20.1)*

1. Fundamental skills of robotic surgery (FSRS): this curriculum was created by the Roswell Cancer Institute in Buffalo, CA, USA, and consists of 4 modules, further subdivided into 16 tasks executed with the aid of the RoSS simulator. Studies have shown the validity of the FSRS curriculum in improving the robotic surgical skills of trainees. It has also been validated for construct validity [11]. The robot-assisted surgical training (RAST), developed by the same center, combines the FSRS with other forms of hands-on training, such as HoST training and wet-lab. Evidence suggests that it has an educational impact on trainees [54].
2. Proficiency-based robotic curriculum: that was developed by the University of Texas Southwestern Medical Center. It consists of an online free tutorial offered by Intuitive Surgical, followed by an interactive hands-on training session on the standard da Vinci system, and finally, the execution of nine inanimate exercises of increasing difficulty. The content, face, and construct validity of this curriculum has been established [49, 55].
3. Basic skills training curriculum (BSTC): It was developed by the University of Toronto and consists of a 4-week training, featuring didactic lectures, theoretical module, 2 hours of hands-on training and exercises at dVSS organized with weekly intervals. This curriculum has been validated and has shown to improve robotic surgical skills [11, 56].
4. The European Association of Urology Robotic Urology Section (ERUS) training curriculum (Fig. 20.1): this represents the first structured and validated curricu-

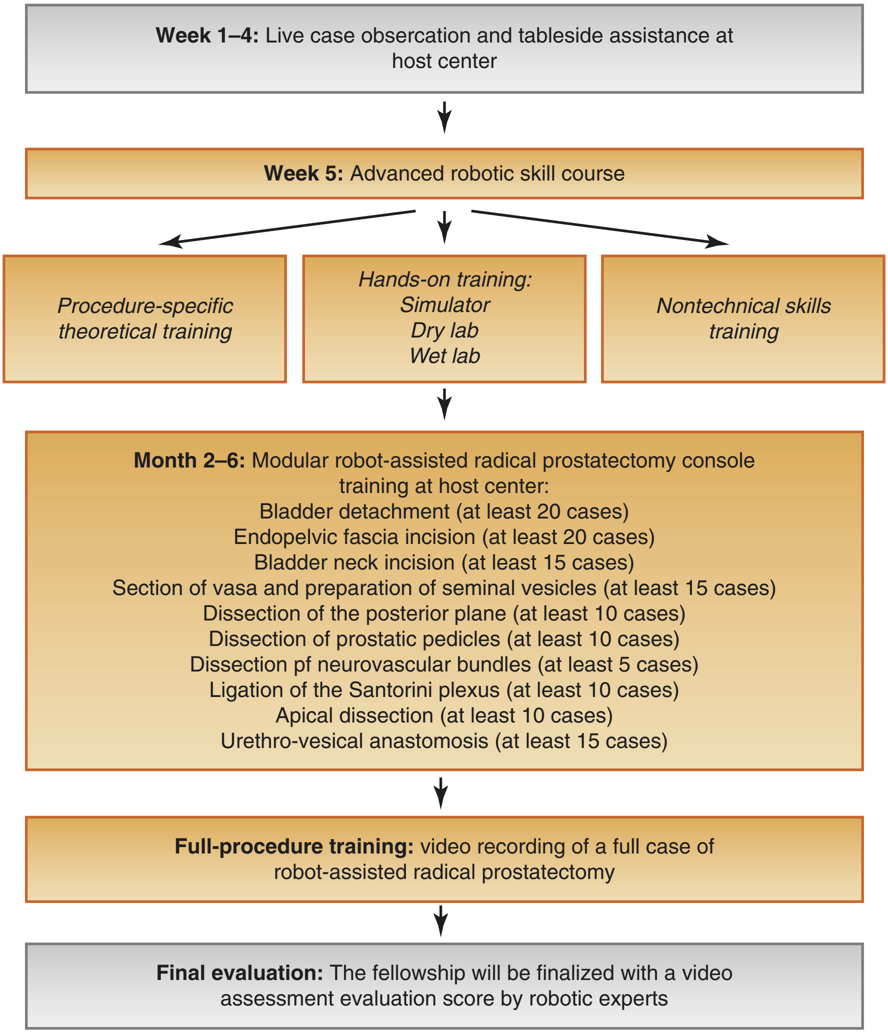

Fig. 20.1 Structure of the European Association of Urology robotic training curriculum

lum in urology. It is built for training on a specific procedure, the RARP. The first version, published in 2015, was followed by a more recent one with a lengthening of the training period from 3 to 6 months. This change is intended to allow even the less experienced trainees to have enough time to continue and finish the full training path [44, 45]. The curriculum initially includes a theoretical study of the robotic platform and the index procedure through e-learning, followed by live case observation and bedside assistance in the host center. At this point, there is a week of intensive hands-on training with virtual simulators, dry-lab, and wet-lab, associated with in-depth theoretical knowledge of technical and nontechnical skills. A recent study by Larcher et al. [57] shows how the use of

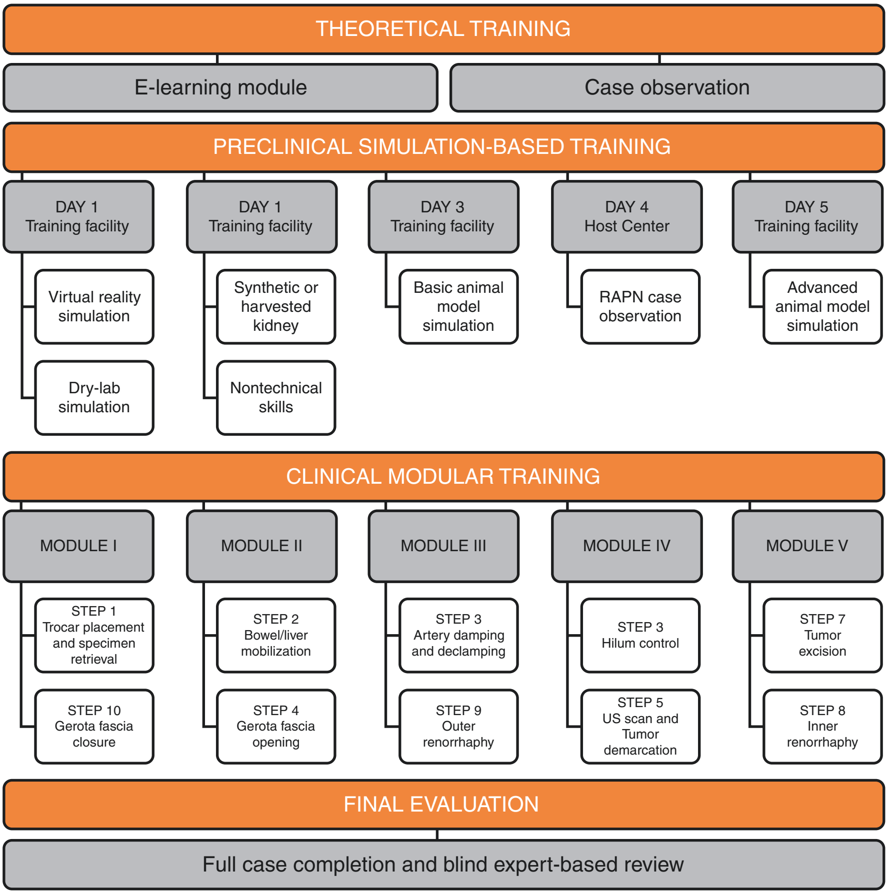

Fig. 20.2 Structure of the European Association of Urology Robotic Urology Section curriculum for robot-assisted partial nephrectomy defined by the modified Delphi consensus process. RAPN = robot-assisted partial nephrectomy; US = ultrasound

virtual simulators in the ERUS curriculum preclinical phase improves surgical performance, according to objective measurement indexes. Moreover, in this study, the average total score and the average improvement score that the trainee should reach to move to the next phase are quantified [57]. Subsequently, the curriculum includes a period of modular clinical training, under the supervision of an expert robotic surgeon, and finally, the surgeon will have to record an unedited video of a complete procedure that will be blindly evaluated using adequate scores [31]. Some studies showed that the fulfillment of the ERUS curriculum leads to an early improvement of results [58, 59].

5. The ERUS curriculum for robot-assisted partial nephrectomy (Fig. 20.2): Based on the ERUS curriculum for radical prostatectomy, the same scientific society

has developed a training program to prepare surgeons to perform robotic-assisted partial nephrectomy (RAPN). This curriculum consists of the first part of theoretical preparation. Second, a week of intensive training with virtual simulators, dry-lab and wet-lab, followed by the third phase of modular clinical training, in which the procedure is divided into 10 steps which the trainee must reproduce. At the end, there is the final evaluation based on the assessment of an unedited video by an expert surgeon in the blind modality. In the pilot validation phase, this curriculum showed no deterioration in the clinical results of the interventions [51].

6. The ERUS curriculum for robot-assisted radical cystectomy (Fig. 20.3): Similarly to the ccERUS for RARP, ERUS also developed a structured training program for robot-assisted radical cystectomy (RARC). The structure of the RARC curriculum was defined as follows: (1) theoretical training; (2) preclinical simulation-based training: 5-day simulation-based activity, using models with increasing complexity (ie, virtual reality, and dry- and wet-laboratory exercises), and nontechnical skills training session; (3) clinical training: modular console activity of at least 6 months at the host center (a RARC case was divided into 11 steps and steps of similar complexity were grouped into five modules); and (4) final evaluation: blind review of a video-recorded RARC case [52].

It is noteworthy that, except for the ERUS training curriculum and the RAPN and RARC curricula, the other validated curricula do not follow the virtual reality simulation phase with dry and wet lab and a modular clinical training phase monitored by an experienced surgeon. This phase appears essential in order to transfer, in a protected and safe setting for the patient, the skills learned on training models into a clinical setting.

An important limitation in these validated curricula is the lack of objective, quantitative assessment tools. The above-mentioned curricula generally use qualitative assessment tools which are prone to high interobserver disagreements and subjective scoring. The development of an objective, quantitative scoring method would make the scoring and comparison of scores more reliable. A possible answer is the use of proficiency-based progression curricula with the implementation of validated, binary performance operative metrics to guide trainees during training and objectively scoring of their operative skills [60].

20.5 Assessment Tools to Evaluate Robotic Skills

Objective and standardized tools that can assess acquired skills are key to developing curricula that can accredit surgeons as being able to perform a specific robotic procedure. At the moment, there are different tools to evaluate the trainees. However, as stated above, it seems increasingly necessary to develop new, simple, objective, standardized, useful, and easy-to-use instruments. The most used tools are:

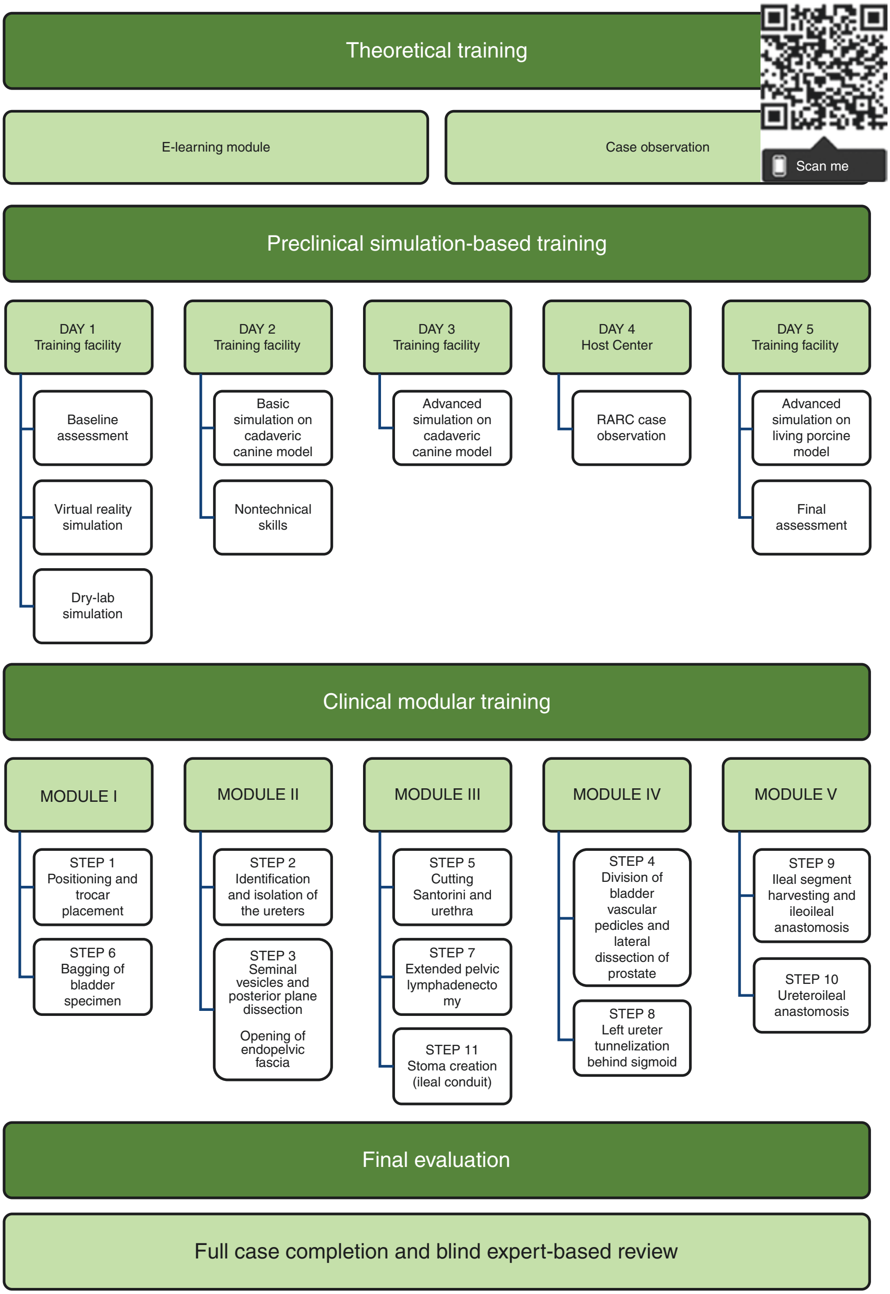

Fig. 20.3 Structure of the European Association of Urology Robotic Urology Section curriculum for robot-assisted radical cystectomy (RARC) defined by the modified Delphi consensus process

20.5.1 Global Assessment Tools

1. Robotic objective structured assessment of technical skills (ROSATS): It is the most commonly used assessment scale in robotic surgery, and it is derived from the objective structured assessment of technical skills (OSATS) in surgery. However, it is a subjective evaluation. In ROSATS, four skill categories are assessed: depth perception and accuracy, force and tissue handling, dexterity, and efficiency. The score assigned for each category is from 1 to 5 [61].
2. Global evaluative assessment of robotic skills (GEARS) (Fig. 20.4): It is developed from a score for the evaluation of laparoscopic intraoperative skills, the global operative assessment of laparoscopic skills (GOALS). Therefore, this instrument was not explicitly developed for robotic surgery but was adapted for this technique. Six domains are assessed by this tool: Depth perception, bimanual dexterity, efficiency, force sensitivity, autonomy, and robotic control. The score assigned for each category is from 1 to 5. Studies showed that this score is a valid, reliable, reproducible measure to evaluate intraoperative robotic surgical skills and is also associated with functional outcomes in RARP [26, 62].
3. Structured assessment of robotic microsurgery skills (SARMS): This is a validated tool. It was adapted to robotic surgery starting from the original structured assessment of microsurgery skills (SAMS) [63].
4. Assessment of robotic console skills (ARCS): It is a validated instrument, consisting of six domains used to verify the adequate acquisition of skills in the use of the robotic console [64].
5. Generic dedicated scoring criteria (GDSC): This is a validated tool used to evaluate the video of a complete procedure performed by the trainees at the end of the ERUS curriculum. The parameters evaluated are instrument use, tissue handling, and errors made. The score assigned for each category is from 1 to 5 [45].

20.5.2 Procedure-specific Assessment Tools

Recently, tools aiming to evaluate specific interventions or steps have been developed. These tools can evaluate both the acquisition of technical skills and the mastery of the procedure, assessing the safety and autonomy of the surgeon in performing the specific intervention. However, to date, no studies have assessed their correlation with clinical outcomes [62]. Specifically, for RARP, we can identify the RARP assessment score, the Robotic Anastomosis Competency Evaluation (RACE), and the Prostatectomy Assessment and Competency Evaluation (PACE) [65–67]. For RAPN, we can identify the RAPN assessment score and "Scoring for Partial Nephrectomy" (SPaN) [68]. For pelvic lymphadenectomy, we can identify the Pelvic Lymphadenectomy Appropriateness and Completion Evaluation (PLACE) [69]. Finally, for cystectomy, we can identify Cystectomy Assessment and Surgical Evaluation (CASE) [70].

Depth Perception				
1	2	3	4	5
Consistently exceeds the target, large movements, fixes slowly.		Some failures in making goal, but corrected quickly.		Directs the instruments in the correct plane to the target.
Bimanual skill				
1	2	3	4	5
Use only one hand, ignores the non-dominant hand, poor coordination between the two.		Use both hands, but the interaction between them is not optimal.		Use both hands in a complementary manner for optimal exposure.
Efficiency				
1	2	3	4	5
Many tentative movements, frequent changes in the thing to do. not progress.		Slow movements, but organized and reasonable.		Confident, efficient, remains focused on the goal.
Force control				
1	2	3	4	5
Jerking, tearing the tissue, damage to structures. Frequent breaking of the suture.		Reasonable handling of tissues, less damage occurs. Occasional rupture of the suture.		Proper handling of tissues, proper traction thereof. Without braking the suture.
Autonomy				
1	2	3	4	5
Unable to complete the procedure		The individual is able to complete the task safety, with some guidance tutor.		Able to complete the task alone, without a guide.
Robot Control				
1	2	3	4	5
No optimizes the position of the hands on the console, frequent collision. The vision is not optimal.		Occasional collision of hand. Vision is sometimes not optimum.		Adequate control of the camera. Optimal hand position without collision.

Fig. 20.4 Global evaluative assessment of robotic skills (GEARS)

20.5.3 Automated Assessment Tools

These tools automatically acquire data during the execution of the exercise by the trainee. They have the advantage of providing an objective, quantifiable assessment, without loss of time by the evaluator. However, further development of this evaluation method is necessary in order to apply it continuously and on a large scale [62].

20.6 Future Perspectives

To date, the structured and modular training model has appeared to be the most convincing. However, the future seems directed toward a new training methodology: proficiency-based progression (PBP) training. The PBP has not yet been applied to robotic surgery, but prospective studies, randomized in other surgical areas, have shown how the application of this approach improves trainees' skillsets by 40–70% compared to the level reached using conventional or traditional training [60, 71]. The application of this training model to robotic surgery might be crucial and result in better preparation of the surgeon for the operating room.

20.7 Conclusion

This recent literature analysis suggests that there is an urgent need to develop and validate new structured training curricula for robotic surgery. This allows them to improve the skills of the surgeons and of their team and to prevent patients from being used as a training module, optimizing their safety. Objective and repeatable evaluation systems and metrics might be used to assess the skills of the trainee and allow the attestation of the skills acquired. The road taken with structured curricula seems to be profitable because it takes into account the various theoretical and practical aspects that must be acquired by the robotic surgeon before fully accessing the clinical setting.

Further refinements in the curricula and some validation studies and reports demonstrating improvement in clinical outcomes since the first phase of learning curves seem to be necessary. However, the tendency to move training out of the operating room should be pursued.

Key Points

- A validated, centralized, and standardized program of robotic surgery training, for each specific procedure is fundamental to guarantee patient safety.
- A structured training curriculum should include theoretical training (e-learning, case observation), preclinical simulation-based training (virtual reality simulation, dry and wet lab), clinical modular training, and a final evaluation.
- At the moment, there are different tools to evaluate the trainees. However, it seems increasingly necessary to develop new, simple, objective, standardized, useful, and easy instruments to use.
- The future seems directed toward a new training methodology: the proficiency-based progression (PBP) training. The application of this training model to robotic surgery might be crucial and result in better preparation of the surgeon for the operating room.

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Chapter 21
Importance of a Training the Trainers (TTT) Course

Ben Van Cleynenbreugel

21.1 Introduction: The Changing World of Surgical Training

An apprenticeship could well be the oldest form of education in the crafts and trades. In the seventeenth century, at the zenith of the master–apprenticeship model in the United Kingdom, the art of medicine was practiced by a heterogeneous group of people. University educated physicians focussed on treating diseases of the inner body through prognostication and the prescription of medicines. Guild-licensed surgeons treated a wide range of ailments through direct manipulation of the body. Besides these, there was a medley of specialists and practitioners who were neither licensed by the authorities nor affiliated with established guilds [1]. For their part, guilds prevented the encroachment of interlopers and foreign practitioners, and they accomplished this through a semiformal educational network, inaccessible to people who were not members of the guild, to train their members to become proficient artisans, morally upright representatives of their guild, and agents of intellectual traditions. Thus, not only did the guilds ensure the quality of their member craftsmen, but they also functioned to limit the number of practitioners of the craft and thereby ensure sufficient work and money for their members.

In the master–apprentice relationship, the master served "in loco parentis." He taught the craft to his pupil and was expected to teach and instruct the apprentice in matters of religion and morality, as well as set a good example for the apprentice to follow. To enforce his will, the master had the right, and indeed the responsibility, to punish recalcitrant apprentices.

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Thus, the choice of a master was critical in an apprentice's pursuit of a successful career, but this important choice was often based on hearsay, since there were no social media or published guides providing information about the various trades and masters. It is not surprising, then, that the ideal father–son relationship between master and apprentice was not always realized. Sometimes, the money needed to pay the tuition for a good master was not available, the apprentice did not tolerate the separation from their families, or perhaps due to a lack of supervision of the master by their family, the apprentice was used and abused as cheap labor.

Toward the end of the nineteenth century, the master–apprentice model changed slowly but surely into a more structured education, thanks in large part to William Halsted, an American surgeon to whom the credo "see one, do one, teach one" is attributed [2]. This credo is frequently quoted but, regrettably, incorrectly interpreted as a license to venture into the wild, exciting surgical world and experiment to one's heart's content. Halsted's intent, however, was to conduct operations in which careful hemostasis and tissue manipulation were central. Until then, little attention had been paid to this, and most operations were performed quickly to prevent the patient from dying during the operation since only rudimentary anesthesia was available. No time was allotted for hemostasis or careful tissue manipulation. Halsted complemented this new approach with a formal surgical training program that placed a strong emphasis on gradually increasing the responsibility and autonomy of the surgeon during training. In exchange for their training, aspiring surgeons were required to show extreme dedication. Marrying was discouraged, and they literally lived in the hospital—24 h a day, 7 days a week—where they received bed, bread, and education in exchange for patient care and hospital service. Hence, the term "resident," because an aspiring surgeon literally resided in the hospital. Only a minority of these residents ever became full-fledged graduated surgeons.

This system was a noticeable improvement over the apprenticeship model, but it created its own problems by allowing overtired, unsupervised residents and interns to treat seriously ill patients without having the proper training, supervision, or skills. This was demonstrated in the infamous Libby Zion case [3] and led to the European Working Time Directive (EWTD), which, as an unintended side effect, significantly reduced the caseload and training opportunities of surgical residents. Indeed, a survey conducted by De Blacam et al. found a 31.8% drop in the mean caseload of European plastic surgery registrars following the implementation of the EWTD [4].

Over time, the training model of learning by osmosis and emulating the master has given way to simulation-based training programs to acquire surgical skills and competency. There is an ever-increasing need for this type of training given the ever-expanding surgical curriculum, the ever-shrinking time for training, and the inexorable growth in accountability.

21.2 Does Surgical Training Provide Better Patient Outcomes?

21.2.1 Trainer Quality Matters

The quality of trainers has been shown to impact a trainee's performance. Better teachers ensure higher test scores for their students. The teaching evaluation scores of faculty have been shown to correlate well with the scores of students on the National Board of Medical Examiners (NBME) for the surgery subject examination [5]. Moreover, students taught by faculty who received poor teaching evaluations, performed worse on Objective Structured Clinical Examination data-gathering stations than students taught by teachers who were rated average or good. Similar findings have been reported regarding the relationship between internal medicine teachers and the performances of their medical students on the NBME for the medicine subject examination scores [6].

These conclusions are in line with the observations of Cohen et al. which showed that good and average teachers maintain stable teaching effectiveness scores over time, but poor teachers can still improve scores if incentives are present [7].

21.2.2 Residency Program Quality Matters

A study by Snowdon et al. showed that direct supervision is superior to the conventional clinical supervision [8]. Data were collected from 290 patients with an acute hip fracture, and patients at the direct supervision site were found to be statistically more likely to mobilize 1 day after surgery and walk further on the fifth postoperative day than patients at the site using clinical supervision.

Still, stating that one residency program is good or better than another can mean different things to different people, but ultimately, it should mean that good programs produce physicians who take good care of patients, and better programs produce physicians who take better care of patients. Ash et al. performed an interesting retrospective analysis of all Florida and New York obstetrical hospital discharges between 1992 and 2007, representing almost 5 million deliveries performed by 4124 obstetricians in 107 US residency programs [9]. They found that women treated by obstetricians trained in residency programs in the bottom 20%, had an adjusted complication rate of 13.6% which was approximately one-third higher than the 10.3% adjusted complication rate for women treated by obstetricians from programs in the top 20%.

21.2.3 Feedback Matters

Feedback, the knowledge of results, is the life-blood of the learning [10]. Used appropriately, feedback from assessments can motivate students and redirect their learning toward areas of deficiency and can help teachers improve their coursework and instructional methods. Feedback will be of particular benefit to a student if it is provided frequently and under conditions that are stress-free and conducive to learning. An assessment that “does not count” is more likely to achieve this aim than one that carries a penalty.

21.3 What Makes a Good Teacher of Surgical Skills?

If we rely solely on studies that have investigated the necessary qualities of a good trainer, we face a number of considerable drawbacks. These studies rely mostly on the opinions of the trainers themselves, are usually limited by small numbers of participants, use trainees from a single specialty, and tend to focus on the addition of technology to the surgical environment to improve training. Critical evaluation of trainers is often downplayed by the faculty and is rarely published so as to protect the reputation of the training program.

Dean et al. conducted a literature review in search of the attributes of a successful surgical trainer [11]. In the 14 retained studies, the traditional stereotype of a loud, demeaning, but academically successful surgeon as an appreciated teacher, was soundly rejected. In contrast, the ideal trainer should be approachable, have patience, be enthusiastic, encouraging, and supportive of the trainee. The trainer should be willing to let the trainee operate and strike a good balance between supervising the trainee and allowing the trainee independence. The trainer should set educational aims and objectives, have the ability to provide appropriate feedback, be capable on a clinical level, and have a good relationship with patients and the healthcare team.

In the process of looking for and fostering excellent trainers, the key element for success is the evaluation of these trainers by their trainees. This is not as easy as it sounds, because trainers are notoriously poor at seeking feedback from their trainees, equally poor at self-reflection, and do not always encourage self-reflection in trainees. These success factors do indeed go against the grain for trainers who were themselves educated in the traditional master–apprenticeship model [12].

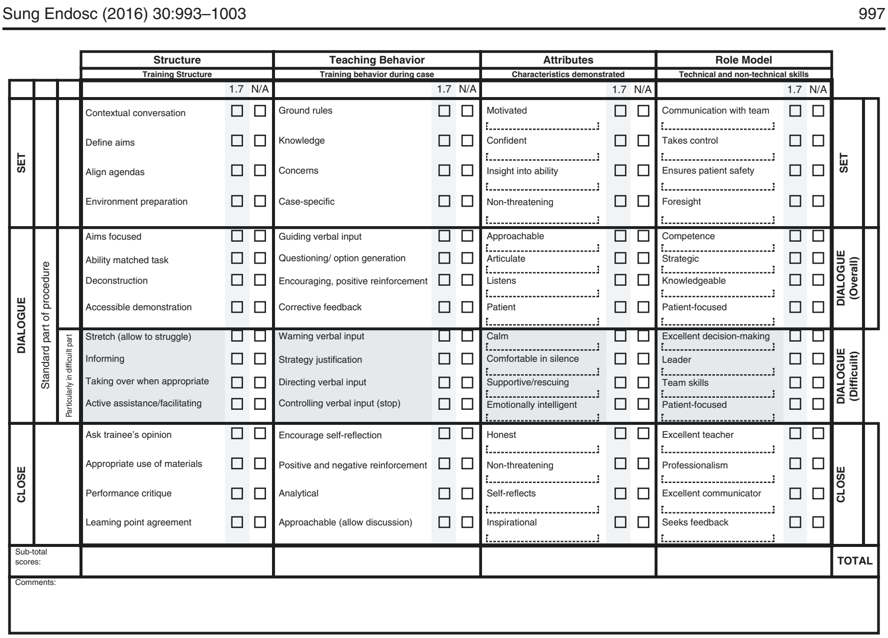
A second problem presents itself in discrepancies observed between the expectations of trainees and program directors regarding the importance of various training elements. Bhatti et al. conducted a survey in 106 accredited otolaryngology residency programs, and four such discrepancies emerged [13]. Residents were in favor of benchmarking a minimum number of cases and for implementing structured and organized methods of training. More importantly, twice as many residents as directors favored simulation-based training. Residents also preferred the opportunity for deliberate practice on simulation more than the program directors. Another difference of opinion between trainers and trainees was that trainees did not want to be taken out of their comfort zone, but they did want to be allowed to struggle. Trainers want the exact opposite. They want to push their trainees beyond their self-set limits in order to effect an improvement in the skills of their trainees [12].

21.4 Ensuring Trainers' Quality

21.4.1 Evaluation of Trainers

As previously stated, the evaluation of trainers by trainees is critical. By providing feedback to trainers, trainers can improve and better meet the needs of the trainees. Maker et al. describe this process, where 44 trainers were divided into three groups: low, intermediate, and excellent, based on the scores they received from 39 trainees [14]. This evaluation process was repeated 6 months later, and based on the feedback, seven teachers demonstrably improved from the low to the intermediate group, and one teacher improved from intermediate to excellent.

Employing a Delphi process, Wyles et al. developed a Structured Training Trainer Assessment Report (STTAR) for evaluating trainers in a lap training program for the colorectal surgery [12]. STTAR consists of four groups, "structure," "training behaviour," "attributes," and "role model" with 16 items in each group for a total of 64 items (Fig. 21.1). Having been designed in the colorectal surgery



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	Structure Training Structure (1.7 / N/A)	Teaching Behavior Training behavior during case (1.7 / N/A)	Attributes Characteristics demonstrated (1.7 / N/A)	Role Model Technical and non-technical skills (1.7 / N/A)	
SET	Contextual conversation	Ground rules	Motivated	Communication with team	SET
	Define aims	Knowledge	Confident	Takes control	
	Align agendas	Concerns	Insight into ability	Ensures patient safety	
	Environment preparation	Case-specific	Non-threatening	Foresight	
DIALOGUE – Standard part of procedure	Aims focused	Guiding verbal input	Approachable	Competence	DIALOGUE (Overall)
	Ability matched task	Questioning/ option generation	Articulate	Strategic	
	Deconstruction	Encouraging, positive reinforcement	Listens	Knowledgeable	
	Accessible demonstration	Corrective feedback	Patient	Patient-focused	
DIALOGUE – Particularly in difficult part	Stretch (allow to struggle)	Warning verbal input	Calm	Excellent decision-making	DIALOGUE (Difficult)
	Informing	Strategy justification	Comfortable in silence	Leader	
	Taking over when appropriate	Directing verbal input	Supportive/rescuing	Team skills	
	Active assistance/facilitating	Controlling verbal input (stop)	Emotionally intelligent	Patient-focused	
CLOSE	Ask trainee's opinion	Encourage self-reflection	Honest	Excellent teacher	CLOSE
	Appropriate use of materials	Positive and negative reinforcement	Non-threatening	Professionalism	
	Performance critique	Analytical	Self-reflects	Excellent communicator	
	Learning point agreement	Approachable (allow discussion)	Inspirational	Seeks feedback	
Sub-total scores:					TOTAL
Comments:					

Fig. 21.1 Structured training trainer assessment report (STTAR)

setting, the STTAR evaluation form is ideal for evaluating trainers of advanced surgical skills. A web-based mini-SSTAR has also been developed based on the same groups and items used for the STARR (Fig. 21.2) and, this mini-SSTAR is suitable for evaluating trainers of basic surgical skills.

Mini-STTAT: Trainee evaluation of trainer

Trainer: Trainee: Level:
Procedure: Previous number of specific procedure:
Total number of cases with this trainer: Hospital:

This trainer:

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree	N/A
Had a structured approach to the training	☐	☐	☐	☐	☐	☐
Agreed clear aims for this training episode	☐	☐	☐	☐	☐	☐
Adjusted training appropriately to level or trainee	☐	☐	☐	☐	☐	☐
Was encouraging	☐	☐	☐	☐	☐	☐
Was non-threatening	☐	☐	☐	☐	☐	☐
Was patient	☐	☐	☐	☐	☐	☐
Provided opportunities to ask questions	☐	☐	☐	☐	☐	☐
Communicated well	☐	☐	☐	☐	☐	☐
Took over procedure when appropriate	☐	☐	☐	☐	☐	☐
Provided too much verbal input (e.g., difficult to concentrate on procedure)	☐	☐	☐	☐	☐	☐
Provided too little verbal input (e.g., didn't always give guidance when required)	☐	☐	☐	☐	☐	☐
Provided too much physical input (e.g., didn't stretch trainee's abilities)	☐	☐	☐	☐	☐	☐
Provided too little physical input (e.g., trainee's abilities over-stretched)	☐	☐	☐	☐	☐	☐
Provided corrective critique during procedure (e.g., criticized but with explanation)	☐	☐	☐	☐	☐	☐
Provided positive critique during procedure (e.g., praised but with explanation)	☐	☐	☐	☐	☐	☐
Encouraged team awareness	☐	☐	☐	☐	☐	☐
Was patient-focused	☐	☐	☐	☐	☐	☐
Encouraged self-reflection on performance	☐	☐	☐	☐	☐	☐
Derived and agreed learning points from the case	☐	☐	☐	☐	☐	☐
Is a good role model with respect to their attitude and behavior (for trainees in general)	☐	☐	☐	☐	☐	☐
Overall is an excellent teacher	☐	☐	☐	☐	☐	☐

Overall, please indicate the extent to which the training met your expectations: Below ☐ Met ☐ Exceeded ☐

Further comments about trainer and/or specific details about case:

	Extremely relevant	Relevant	Neutral	Irrelevant	Extremely Irrelevant
Overall, how relevant did you find this form?	☐	☐	☐	☐	☐

How long did it take you to complete it? ☐☐ Minutes

Fig. 21.2 Mini-Structured Training Trainer Assessment Report (mini-STTAR). Items can be split into different groups "structure" [1–3], "training behaviour" [9–15], "attributes" [4–8], "role model"

21.4.2 A Remedy for Bad Trainers

The Royal College of Surgeons of Edinburgh proposes the concept of a trainer's journal to monitor and improve, where necessary, trainer quality across seven training domains [15]. These include (1) ensuring safe and effective patient care through training, (2) establishing and maintaining an environment for learning, (3) teaching and facilitating learning, (4) enhancing learning through assessment, (5) supporting and monitoring educational progress, (6) guiding personal and professional development, and (7) continuing professional development as an educator. These training domains form the template for a trainer's journal, lay the foundation for (self) evaluation, and serve as a useful guide, enabling a trainer to improve their craft. The proposed pathway to ensure and improve trainer quality is outlined below.

- All trainers should be formally reviewed on a 5-year cycle.
- Clinical Supervisors should meet 100% of the "effective" standards in domains 1, 2, 3, 4, and 7 over this 5-year cycle.
- Educational Supervisors should meet 100% of the "effective" standards in all seven domains over this 5-year cycle.
- All trainers should aim to provide some evidence within each of their relevant domains annually.
- A trainer who fails to generate satisfactory evidence in any relevant domain must provide evidence for that domain in the next year.
- A trainer who fails to meet 60% of the standards or has major deficiencies in a particular area at a formal review should undergo further review in a shorter time period, e.g. 12 months.
- Trainers who consistently fail to meet 80% of the standards at an effective level should re-examine their role as a trainer.
- Any trainer acting in a senior role, e.g., Training Programme Director, should meet 100% of the standards at an effective level and a major proportion at an excellent level.

21.5 Conclusion

The surgical craft is no longer learned on real patients in the operating room, and the traditional master–apprenticeship model has given way to simulation-based surgical training in dedicated training facilities outside the operating room. The quality of this type of training is improved when using direct supervision and formative feedback, which, in turn, leads to better patient outcomes.

To ensure optimal trainer quality, it is crucial to provide feedback to the trainers on their performance. Feedback allows trainers to improve the quality of the training they give. If trainers fail to do so, a remedy trajectory can be followed.

Key Points
The surgical craft is no longer learned on real patients in the operating room, and the traditional master–apprenticeship model has given way to simulation-based surgical training in dedicated training facilities outside the operating room. With the right setup, this improves patient outcomes.

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Chapter 22
Feedback and Debriefing

Sunjay Jain

22.1 Introduction

> If you don't get feedback, your confidence grows much faster than your accuracy—Phillip Tetlock, Superforecasting

The aim of any sort of training is to improve performance. The degree of improvement will be influenced significantly by the way in which this training is structured, and the key to success is the ability to reflect on performance and change those aspects that are suboptimal.

Kolb [1] described experiential learning, explaining that effective learning takes place through REFLECTIVE PRACTICE followed by CONCEPTUALISATION—reinforcement or modification of behaviors and then EXPERIMENTATION—testing these ideas in practice (Fig. 22.1). This then leads to the CONCRETE EXPERIENCE.

When trying to improve, there are different levels of reflective practice that can be undertaken. The simplest is deliberate practice. The example here would be, for example, a trainee surgeon practicing laparoscopic suturing using a laparoscopic trainer. By repeating the exercise many times, one would expect speed and accuracy to improve.

During deliberate practice, it is possible that difficulties may be overcome by developing workarounds that can limit the level of competence that can be achieved. This would be like a golfer who has a reasonably effective swing but cannot develop further unless they "unlearn" some bad habits. This is why feedback and debriefing are important.

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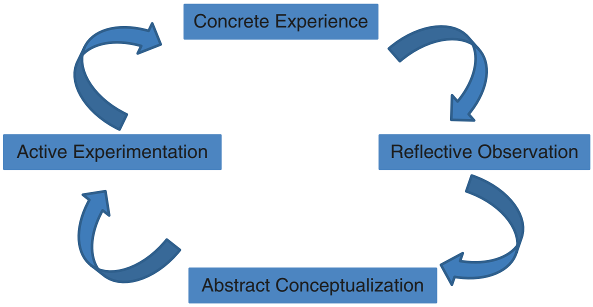

Fig. 22.1 Kolb's learning cycle

Table 22.1 Comparison of feedback and debriefing

	Feedback	Debriefing
Relationship	Hierarchical	Flat
Timing	Quick/efficient	Slow/involved
Mode	Information	Discussion
Retention	Shorter	Longer
Requires	Acceptance of Teacher/student relationship	Control Dynamics Facilitation
Suited to …?	Practical skills	Non-technical skills Teams

Adding expert feedback to a teaching exercise greatly increases its value [2]. Sadler [3] described the purpose of feedback as reducing discrepancies between current performance and a goal. Generally, there is a clear distinction between student and teacher when feedback is given, with a hierarchical relationship. Indeed, the credibility of the individual giving feedback in the eyes of the receiver will have a bearing on its effectiveness [4].

How does debriefing differ from feedback? In the context of simulation, debriefing is usually seen as a more detailed and immersive process. While often there will be a distinction between the student and teacher, the process of debriefing is more facilitative with less hierarchy (Table 22.1). Debriefing particularly lends itself to complex situations such as moulage and non-technical skills training [5]. Having said that, it is possible to have a debrief on even the lowest fidelity simulation. What matters is that the analysis of performance is more nuanced than simply the view of the trainer and takes into account the views of the trainee and others who were observing.

22.2 Feedback in Practice

Skillfully given feedback can be transformative; however, we can all think of examples of poor feedback. An offhand comment saying we did fine, but nothing more. Being scolded for poor performance, but with no advice on how to improve. Why is feedback often a disappointing experience?

While receiving feedback can, of course, be stressful, the stress and anxiety of giving feedback are underestimated. Indeed, it can be so hard that it is simply avoided. It is understandable that, faced with a challenging situation, it may feel safer to say nothing than to say the wrong thing. Justification for this can be that the shortcomings were a one-off or that hopefully, someone else will deliver the feedback better. Unfortunately, this will result in a lost learning opportunity. If the trainee is unable to reflect, they cannot progress through Kolb's learning cycle.

In modern medical training, particularly in simulation, there is an expectation from learners that they will get good quality feedback but many trainers feel unprepared to deliver this. When students are asked what could be improved about their feedback experience, two general themes emerge. Firstly, they are keen that their strengths are acknowledged, that the feedback does not just focus on what needs to be improved. Secondly, they feel that they should be listened to, that the feedback should be a two-way process, and that the next steps should be planned together. We will now review some of the principles for giving effective feedback.

22.2.1 Principles for Effective Feedback

The best known rules for giving feedback are Pendleton's rules [6]. These consider the above principles and employ what is often described as a "sandwich" technique.

1. Ask the trainee what went well
2. The trainer states what went well
3. Ask the trainee what could be improved
4. The trainer states what could be improved
5. An action plan is agreed

For those inexperienced at giving feedback, they do provide a framework to ensure that the conversation includes positives and that a plan for the next steps is discussed. Another method that is often used is the SHARP toolkit (Fig. 22.2) which was developed at Imperial College London [7, 8]. Using this structured approach has been shown to improve the quality of feedback given to trainees.

When giving examples of behaviors that need improvement, it is always best to focus on behaviors that were seen and be non-judgmental. Other things to consider when giving feedback include [9]:

- Ensure the learner is prepared to receive feedback
- Have adequate time and appropriate location

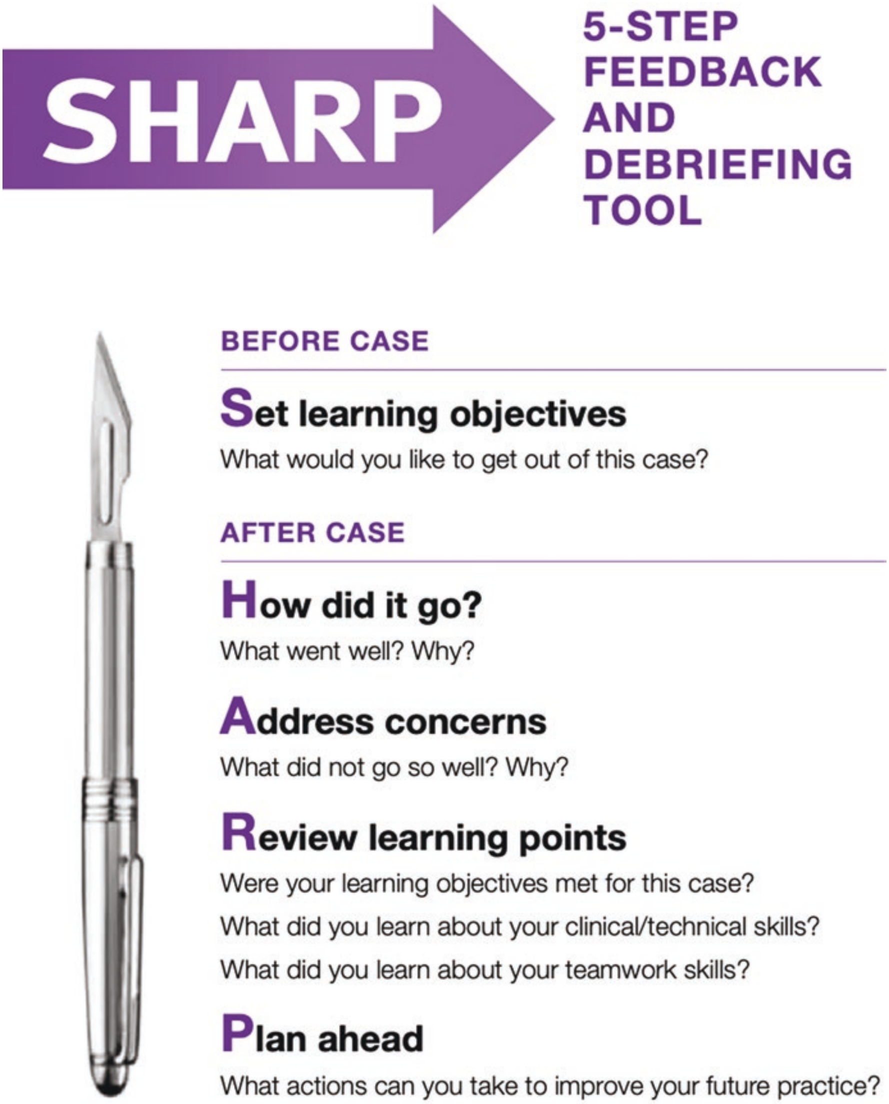

Fig. 22.2 The SHARP method of giving feedback. Taken with permission from: Imperial College, London. *The London Handbook for Debriefing: Enhancing Debriefing in Clinical and Simulated Settings*. London: Imperial College, 2010

- Be specific and honest
- Aim to give feedback as soon as practical after the event
- Ensure learning goals are SMART (specific, measurable, achievable, realistic, time-limited)
- Ensure the messages have been taken in by asking the learner to summarize the discussion
- Document the discussion

22.2.2 Unconscious Bias

Unconscious bias is increasingly recognized as a potential pitfall in medical education [10]. As the name suggests, this kind of behavior is not something that those giving feedback would be aware of but is influenced by preconceived perceptions of what is expected from individuals according to race, gender, or other characteristics. In the business sector, there is evidence that women tend to get more vague feedback [11] and this was also the case in a study that looked at gender differences in feedback given to trainees in emergency medicine [12].

The rest of this chapter will concentrate on describing debriefing as it applies to simulation, how it is performed, different approaches and its effectiveness.

22.3 How Debriefing Is Performed

As stated earlier, debriefing is a dialogue between two or more people and is particularly relevant for assessing performance in more complex scenarios. The focus of improvement can be at the individual, team, or system level. In urology, it has been successfully used during a urology bootcamp for new residents, in modules that incorporated emergency scenarios [13] and also a simulated ward round [14].

While debriefing does follow the general rules for giving feedback as described above, often several individuals are taking part, and so it generally requires facilitation to ensure it covers all the areas required and also does not drift into irrelevant discussions. This requires skill and training, something that is covered later. A general structure for a debriefing session is shown in Table 22.2, based on Ahmed [15], Jaye [16], and Phrampus [17].

22.3.1 Pre-Briefing

One of the advantages of debriefing in simulation is that there is the opportunity for a “pre-briefing” before the activity where the scene can be set and ground rules can be discussed. There is evidence that doing this enhances the effectiveness of the

Table 22.2 Structure of a debriefing session

Phase	Key features
Pre-briefing	• Plan session • Set learning objectives • Establish psychological safety • Explain "rules"
Reaction	• Describe what happened • Ensure a shared mental model • Deal with clinical questions • "Park" issues that are not pertinent to the learning objectives • Allow emotions to be expressed
Analysis	• Reflect on actions • Open questions • Use silence • Encourage group participation • Use good judgment
Summary	• Review if learning objectives have been met • Formulate a development plan • Plan a review timetable

debriefing and ensures maximum information is obtained. There are key elements to a pre-briefing. The concept of psychological safety has been coined to describe how a facilitator can ensure that participants feel able to perform and subsequently discuss events candidly without fear of a negative impact on their self-image or professional status. Rudolph [18] discussed establishing a "safe container." The pre-briefing also ensures learning objectives can be clearly discussed. Other "rules" to discuss at the pre-briefing are establishing that this is an interactive exercise requiring the participation of all, that the focus is on improving performance rather than highlighting inadequacy, and that all discussion is confidential [19].

22.3.2 Reaction

This is sometimes called the "description phase" and is the initial part of the debriefing where the facilitator generally elicits the viewpoints of participants. This is done by asking them to describe the events that took place, at this stage trying to avoid too much scrutiny of the detailed reasons why things were done. It enables the group to clarify the sequence of events and what issues will need to be addressed in the analysis phase. It also allows emotions to be expressed; the reasons for these can then be explored later. Sawyer [20] describes establishing a shared mental model, in order that all participants are looking at things from the same perspective.

The facilitator needs to ensure that all pertinent areas are covered, while also making sure not too much time is spent on aspects that will not aid learning. For example, often participants focus on specific clinical questions, it may be necessary to "park" some issues, perhaps to return to them later in the debrief.

22.3.3 Analysis

In this part of the debrief, the actions of those participating are evaluated. This requires the facilitator to use their skills to draw out the reasons for particular behaviors and allow any gaps between actual and desired performance to be identified. The participants are encouraged to reflect on their actions and be honest with each other about areas that need to be changed or improved. The methods used are similar to the communication skills used by doctors with their patients. For example, closed questions should be avoided in order to ensure learners are able to self-assess their performance. Rather than saying "did you realise the patient was bleeding?" which could have a yes/no answer, the question could be "how did you interpret the change in clinical signs?" There might be times in this phase where there are periods of silence and it is important to be patient as during this time, participants are formulating their thoughts and analyzing their actions. There has been some debate about whether facilitators should withhold or contribute their own opinions on how things went during the simulation. The former approach aims for the participants to discover these on their own, hoping that they are more likely to learn if they are able to work out their own mistakes. Unfortunately, it is very difficult for those leading the debrief to avoid giving subtle clues about their opinions, often non-verbal. This can create a situation where there is reticence or fear to discuss mistakes and so an alternative method of debriefing with good judgment has been proposed [21]. Here the facilitator is honest about what they see as errors and explores what was going on in the participants' thought processes during that time.

22.3.4 Summary

The summary phase is where the group reflects on how well the objectives of the simulation have been met and discusses the practical ways in which future performance can be improved. The facilitator should ask the group to describe the lessons learned from the exercise, with their thoughts on the next steps. Subsequently, the aim would be to jointly come up with a development plan that contained specific, achievable actions to enhance performance. Having a defined review date where progress can be assessed is important, and this might be by assessing competencies in clinical practice or using another simulation.

22.4 Different Approaches to Debriefing

There have been several articles reviewing different methods of debriefing [20, 22, 23]. Sawyer [20] classifies debriefing into three categories: Facilitator guided post-event debriefing, self-guided post-event debriefing, and facilitator guided within event debriefing

- *Facilitator Guided post-event debriefing:*

  This is by far the commonest method of debriefing. It involves one or more trained facilitators guiding the session. Most descriptions of this method comprise a pre-brief followed by three phases broadly corresponding to the structure described above. Some groups have increased the number of phases to provide a more structured approach, including a section to discuss clinical issues [24], emotional reactions [25], or benchmark performance against expected standards [26]
- *Self-guided post-event debriefing:*

  As suggested, in this approach, the participants themselves facilitate the debriefing. Usually, this requires guidance and a framework within which to do it. In a randomized trial of 120 subjects, this method resulted in equivalent outcomes as measured by improvement in performance on repeat simulation [27]. The use of video and clear instructions on how to structure the debrief meant that facilitators were not required, saving on resources.
- *Facilitator guided within event debriefing*

  With this form of debriefing, rather than waiting until the entire simulation scenario is completed, it is paused at an appropriate point to provide real-time feedback to participants. One area where this has worked well is when learning cardiopulmonary resuscitation skills, allowing rapid repetition of procedures after feedback to try things again [28, 29]. Within urology, this technique was used during a simulated ward round to allow a "freeze-frame" approach where individuals took turns in being the doctor as the scenario unfolded [14, 30]. This allowed more participants to take part in the scenario, with debriefs pertaining to each individual being done in a timely manner.

22.4.1 Virtual Debriefing

The COVID Pandemic has made any sort of simulation and subsequent debriefing more difficult [31]. The immersive and interactive nature of a debriefing is difficult to replicate online. This does not preclude effective debriefing, however, as long as the potential barriers (cognitive overload, lack of non-verbal cues, distractions, etc.) are appreciated. Cheng et al. [32] set out how an educator can take steps to maximize the success of a virtual debrief.

22.5 Effectiveness of Debriefing

While there is extensive literature describing how to perform a debriefing after a simulation, what actually happens in practice may not match what was planned. Potential barriers to effective debriefing include inexperience or lack of preparation of facilitators, limited time, and lack of engagement of participants. Krogh et al. [33] performed a qualitative interview study of debriefing faculty to explore these issues. They proposed various qualities required for effective debriefing. In particular, they described "artistry," the ability to be flexible, use a variety of techniques and think on your feet. Other groups have produced objective criteria to assess the quality of debriefing [34–36]. These allow observers to rate facilitators on key aspects such as establishing a learning environment and providing appropriate analysis and steps for improvement. Cheng et al. [37] suggest that peer coaching is a practical way to develop debriefing skills. Ultimately becoming skilled in debriefing will take time and is a journey through various stages of development. Initially, as a novice, it is useful to spend time with more experienced debriefer's in an apprentice type relationship before reaching competence and eventually expert status [38].

Two systemic reviews on the effectiveness of debriefing [39, 40] have highlighted the variability in methodology and the difficulty in demonstrating objectively that debriefing changes the outcomes of simulation-based education. Further research is required in this area, in order to help define the optimal methods to deliver this resource.

22.6 Summary

There is no doubt that feedback and debriefing are essential to get the most out of a learning experience. Doing these things well is not easy; however, sticking to basic principles, the use of a structured approach, and being aware of the potential pitfalls will give the best chance of a good outcome. Ultimately, though, there is no substitute for observation and experience, which will allow progression from novice to proficient and eventually expert.

Key Points

- Feedback or debriefing is essential after any simulated training exercise in order to maximize the chances of improvement.
- Giving feedback requires skill, and being aware of potential pitfalls is essential.
- Debriefing after simulations requires involvement of all those taking part and needs to be facilitated using a structured approach.

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Chapter 23
Costs in Surgical Training, Does It Outweigh the Benefits?

Tiago Oliveira, Afonso Castro, and Sérgio Pereira

23.1 Introduction

23.1.1 Traditional Surgical Training

Surgical training is a complex and unique process that requires not only academic and scientific learning but also technical and non-technical skills training. While academic and scientific learning is fairly similar in all medical areas, technical skills training is the centerpiece of surgical education and has therefore been the focus of most surgical training models.

After being appointed as a Surgeon-in-Chief of the Johns Hopkins Hospital, in 1889, William Stewart Halsted established a graduate training program for surgeons that was replicated throughout the world, influencing surgical training over the following century [1, 2]. Halsted's pyramidal surgical training program was a highly competitive and hierarchical process, in which a series of residents, available 24 h a day, 7 days a week, learned the surgical trade under the guidance of a single experienced surgeon [1, 2]. With no previously defined duration or formative plan, the program placed great emphasis on observation and learning from experience with patients [1, 2]. Throughout the training process, less capable residents were eliminated, and only the most capable progressed to subsequent phases and received increasing responsibility, culminating in the full training of a single experienced surgeon [1, 2].

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Despite the obvious qualities of Halsted's surgical training program, it was not devoid of flaws. In fact, despite being effective in the training of an experienced and autonomous surgeon, Halsted's program was highly inefficient, because the necessary byproduct was a considerable number of eliminated candidates that were only partially trained in the art of surgery [1, 2].

One of the fiercest critics of Halsted's model was Edward Delos Churchill, Chief of Surgery of Massachusetts General Hospital [1]. Churchill opposed Halsted's surgical training program due to its indefinite length, its strenuous competition for a single resident position, and the fact that it depended on a single chief of service [1]. In order to surpass the limitations of the pyramidal surgical training program, Churchill developed a rectangular surgical training program, in which a series of carefully selected residents were trained over a 5-year period, under the guidance of several experienced staff surgeons, as they rotated through the different surgical departments of the hospital [1, 3]. Assuming they performed satisfactorily, all residents completed the five-year surgical training program [1, 3].

Taken together, Halsted's pyramidal model and Churchill's rectangular model revolutionized surgical training and formed the basis of surgical residency programs throughout the world for most of the twentieth century.

23.1.2 Problems with Traditional Surgical Training

During the late twentieth century and the beginning of the twenty-first century, several highly mediatic malpractice cases drew public attention to the downsides of traditional surgical training models, namely in terms of residents' lack of proper supervision and fatigue (due to long working periods) [4]. This situation led to the implementation of several national regulations restricting weekly and daily working hours for medical residents [4]. Considering that traditional surgical training programs depended on long working periods, this regulatory limitation of residents' working schedules had a drastic impact on surgical education [4, 5].

In fact, not only there was a subjective decline in residents' performance (perceived both by program directors and residents themselves), but there was also an objective decline in proficiency and autonomy levels at the end of residency programs [6–8].

On the other hand, the fact that traditional surgical training programs were based on learning from experience with patients posed many ethical dilemmas regarding patient safety, as well as insurance-related issues [4, 5].

Altogether, these issues posed a considerable challenge to surgical residency programs, one that would lead to a major paradigm shift in surgical training worldwide.

23.1.3 Simulation-Based Surgical Training

In light of the limitations of traditional surgical training, over the past decades, simulation-based training has been extensively explored and used as an adjunct to traditional surgical training, namely for the development of technical skills via individual hands-on practice [5]. Various types of simulation-based surgical training can be considered: dry-lab simulation training, wet-lab simulation training (including *ex vivo* animal models and live animal models), virtual reality simulation training, and cadaveric simulation training [9].

Simulation-based training has been shown to improve operative skills of trainees [10, 11]. Furthermore, evidence suggests that the skills acquired through simulation-based training transfer to operative settings [10, 12]. A critical review of simulation-based medical education research identified the following requirements that must be present in order for simulation-based training to be beneficial: the simulator is embedded in a controlled environment, the simulator permits individualized learning, the simulator is a valid approximation of clinical practice, the simulation is integrated into an overall curriculum, learning outcomes are clearly defined and measured, feedback must be provided during the learning experience, trainees must engage in repetitive practice, and trainees practice with increasing levels of difficulty [10]. If these principles are ensured, there is evidence that repetitive practice involving medical simulations is associated with improved learner outcomes, with more practice yielding better benefits [10].

23.2 Simulation-Based Surgical Training in Urology

23.2.1 Traditional Surgical Training in Urology

Urology residency training is quite heterogeneous throughout the world, not only in terms of the total duration of training but also in terms of the length of core surgical training, the length of specific urological training, research requirements, working hours, surgical exposure, and evaluation methods [13, 14]. However, regardless of the regional or national differences, urology residency programs are always long and demanding training processes.

Although there is no accurate calculation of the actual cost of a surgical residency program, Cooper estimated it to be around 80.000USD per resident per year on average [15]. Given the considerable increase in technology use and subspecialization in urology over the past decades, it seems reasonable to think that the value should be even higher for urology residency programs.

23.2.2 Problems with Traditional Surgical Training in Urology

A study by Carrion and colleagues evaluated the current status of urological training among final-year residents in Europe [16]. Altogether, the surgical exposure of residents to procedures seems low, with only 50% of residents performing more than 20 procedures like TURP, TURBT, or circumcision and less than 5–10% performing more than 10 procedures like PCNL, radical nephrectomies, partial nephrectomies, radical prostatectomies, or radical cystectomies. Overall, only 30% of residents were satisfied with their surgical training, and 14% believed they performed enough surgeries during their training. Furthermore, confidence in performing procedures without supervision was associated with higher surgical caseloads, while satisfaction with training was associated not only with higher surgical caseloads but also with working less than 50 h/week and with laparoscopic training [16].

A systematic review of laparoscopic training in urology residency programs, encompassing evidence from almost 1000 residents, identified wide variations in terms of exposure to laparoscopy between training programs, with most residents considering that training was inadequate and having low degrees of confidence in independently performing laparoscopic procedures by the end of the residency [17].

Altogether, these studies show that, despite the considerable costs associated with traditional surgical training, current urology residency programs have limitations that may seriously compromise the quality of urological training over the next few years.

A recent systematic review and meta-analysis on the prevalence of preventable patient harm across medical care settings, identified a 6% pooled prevalence of overall preventable patient harm, reaching up to 10% in the case of surgical preventable patient harm [18]. In terms of costs, even when only the length of stay is considered, postoperative events can incur in 13.000 to 57.000$ of excess charge, due to a 4 to 11 day increase in the length of stay [19]. Considering that most surgical complications occur during the initial learning curve, ethical concerns about patient safety have driven the need to develop alternative surgical training methods [20, 21].

23.2.3 Simulation-Based Surgical Training in Urology

In order to surpass the limitations of traditional surgical training in urology, several simulation-based surgical training models and programs have been developed [21, 22]. Conceptually, simulation-based surgical training models can be organized according to:

- The skills being trained: technical skills and non-technical skills;
- The procedures being trained: open, lower urinary tract endoscopy, upper urinary tract endoscopy, percutaneous, transurethral resection, laparoscopy, robotic, female urology, ultrasound, and biopsy;
- The type of simulator being used: dry-lab, wet-lab, virtual reality, cadaveric.

In terms of quality, simulation-based surgical training models can be assessed in terms of face, content, construct, concurrent, and predictive validity [21].

23.3 Technical Skills Training in Urology

In order to allow a more structured analysis of the subject, technical skills training in urology will be organized according to the type of simulator being used: dry-lab, wet-lab, virtual reality, or cadaveric.

23.3.1 Dry-Lab Simulation Training

There is a wide range of models available for simulation covering a substantial number of urological procedures [23, 24]. From cheap, homemade, low-fidelity training models to hi-tech/hi-cost/high-fidelity simulators [23, 25], allowing the training of basic single skills, such as skin suture or bladder catheterization, as well as complex procedures in immersive high-fidelity simulators that also explore non-technical skills, such as leadership, communication, and teamwork [23, 25].

The benefits of simulation in the acquisition of technical skills in urology are well established [26, 27]. In recent years, well-structured and organized training programs, for example, European Basic Laparoscopic Urological Skills (EBLUS) or Endoscopic Stone Treatment Step 1 (EST-S1), have gained popularity [28, 29]. Moreover, the use of inexpensive standard models in laparoscopic boxes or low-cost portable bench-top models for flexible ureteroscopy has the added value of allowing trainee assessment [29, 30].

A review by Preece stressed that repeated training in face, content, and construct validated high-fidelity bench-models improved resident performance in several steps of a collection of urological procedures: cystoscopy; ureterorenoscopy; Transurethral Resection of the Prostate/Bladder tumor (TURP/TURBT); Holmium Laser Enucleation of the Prostate (HoLEP); percutaneous renal access; and laparoscopic/robotic procedures [23]. On the other hand, whether these simulators can improve real operating performance is harder to prove, as randomized trials face potential ethical problems [23]. Nevertheless, there is wide evidence of the benefits, such as decreased procedure times and errors [27].

In theory, high-fidelity bench-top models appear as a low-cost alternative to high-end virtual reality simulators. In endourology, for instance, it has been shown that trainee performance was similar after training in high-fidelity models or virtual reality simulators [31]. However, sometimes bench-top models have hidden costs. Chou et al. compared the Simbionix URO Mentor™ virtual reality simulator® ($80.000) versus the Limbs & Things ureteroscopy training model® ($3.135). The former's higher acquisition price was outweighed by the latter after adding the costs of the necessary endoscope, ancillary equipment, and expert clinician availability

[31]. In a different setting, a 3D-printed model for vesicourethral anastomosis was presented by a fraction of the da Vinci® Skills Simulator, but costs from an available console must be taken into account [32].

As outlined in Chapter 7, there is a wide range of models available, with different reliabilities and price tags. Does the price reflect the performance? There are several examples of low-cost models that equal the performance of high-cost models. The previously mentioned Limbs & Things ureteroscopy training model® ($3.135) and a $20 homemade low-fidelity model had no significant difference in global rating scores, checklist scores pass rating, and time to complete the stone-removal task [33].

Simulation has become a cornerstone in urological training; however, access to simulators across Europe has been decreasing [24]. A recent communication showed that the availability of laparoscopic trainers in academic departments decreased from 47% to 41% from 2014 to 2018, while the availability of ureteroscopy and trans-urethral resection simulators decreased from 17% to 5% in the same period [34].

There have been reports of cheap models that could solve the availability issue [24]. A systematic review identified 20 articles describing bench models under $150, comprising different procedures: suprapubic catheterization (6), percutaneous nephrolithotomy (5), cystoscopy (3), transurethral resection of the prostate and bladder (2), scrotal examination (1), circumcision (1), ureteroscopy (1), and open prostatectomy (1). There was no evaluation of the transferability of the skills to real patients, but almost all (90%) accessed face, content, or construct validity [24].

Rowley et al. explored the effectiveness of surgical simulators created using household items. Simulation of wound closure, open prostatectomy, delicate tissue handling, and knot-tying was achieved using household items, such as banana peels, beverage cans, oranges inside up-side-down bottles, and overcooked pasta. Although these cheap, innovative solutions cannot replace more expensive but validated models, they may be a valid option in areas with limited resources (discussed in Chapter 16) [25].

Dry-lab simulation gained a prominent place in urological training [26]. Its role in the certification of urologists will most likely increase as well [27]. Low-cost models are likely to be particularly valuable to novice trainees, as they require little in terms of expense or labor, do not require any sacrifice in terms of study budget or departmental resources [24].

23.3.2 Wet-Lab Simulation Training

Wet-lab simulation using live animal models and ex vivo animal models has been classically used in various medical specialties, namely urology, ophthalmology, cardiac surgery, and pneumology, among many others. It provides high-fidelity training and higher improvement rates in technical skills, compared to low-fidelity models. Simulation training on live animals provides full procedure simulation and can mimic complications, especially vascular ones, in a less stressful environment, although it has some drawbacks, namely the need for specialized equipment and facilities, high costs, ethical-related concerns, and some anatomical variation that animals can present. Using inanimate models, by contrast, is generally reproducible, safe, portable, and readily available [35–38].

Palter et al. and Shetty et al. indicated that animal and cadaveric models are preferred by resident trainees, in comparison to virtual reality simulators [37, 39]. Ex vivo animal models showed more cost-effectiveness compared to animal or cadaver simulators [35].

Wet-lab models have been widely used in endourologic procedure training. Following the growing evidence that TURBT performance has a prognostic impact on bladder cancer treatment, the Asian Urological Surgery Training & Education Group used porcine bladder to create an ex vivo model where piecemeal and en-bloc resection practice was available, providing a validated simulation model with an estimated total cost of $232, which is considerably less expensive compared to other models, like the Simbla TURBT simulator® or Limbs & Things® [40].

Hou et al. mimicked prostate tissue by using porcine kidney and created a TURP training model that enables proper anatomical landmarks and use of electrosurgery with a cost estimated at around $110, which is less than other TURP simulation models, concluding this is a cost-effective option [41].

Regarding urolithiasis treatment, there have been many wet-lab simulation models created. A systematic review by Brunckhorst et al. in 2015 stated that porcine models were developed and validated for upper urinary tract endourology training. Soria et al. reported both live and ex vivo porcine models for ureterorenoscopy simulation. Information regarding cost-effectiveness is still scarce, although it will be difficult to surpass that some low-fidelity models have shown a similar educational impact, with costs 185 times lower than the high-fidelity simulator Uro-Scopic Trainer® [42–45].

With the increase in the trend for minimally invasive surgery, there is a growing demand for laparoscopic and robotic-assisted surgery simulators. A survey by Shetty et al. showed that, for residents, live animal models are the preferred simulation tool for laparoscopic training, compared to ex vivo, virtual reality, or dry-lab models [39]. Several live animals and ex vivo simulators are available. In 2006, Laguna et al. made use of chicken esophagus and stomach associated with Pelvic Trainer® in order to validate a wet-lab model for urethrovesical anastomosis training [46]. Later, Ramachandran et al. used the same model to recreate a laparoscopic pyeloplasty, providing a cheap ex vivo model for basic and advanced skills. Similar procedures were developed with porcine parts [47–49]. Live animal models provide a more realistic simulation environment, with the presence of proper anatomical landmarks, circulation, bleeding, and pneumoperitoneum [50]. Molina et al. developed a live rabbit model that enabled trainees to perform nephrectomy, hysterectomy, cystectomy, and aorta and vena cava dissection, which showed a very attractive and all-around model for basic and advanced laparoscopic procedures [51]. Other authors reported laparoscopic nephrectomy training using live porcine models, with good result [52]. Despite high-fidelity and advanced skill practice are some of the features favoring live animal training, the high cost associated with developing a training center, preparing the animal, and legal and ethical dilemmas are important drawbacks, impeding its generalized use in surgical training in urology [48, 49].

Hung et al. described a partial nephrectomy model using a porcine kidney and foam ball mimicking a renal tumor in the da Vinci Skills Simulator®, which successfully allowed trainees to develop skills for tumor resection. Excluding its high cost, this model was highly cost effective, since the cost of the kidney model was $15 and its construction time was rounded to 7 min [53].

23.3.3 Virtual Reality Simulation Training

Virtual reality (VR) was created to closely mimic real-life scenarios. The increasing demand for high-quality health care, low cost, and legal issues does not allow for training in real-life patients. As a result, simulation training, namely with the use of VR, is increasingly gaining importance, so that urology trainees can acquire as many skills as possible before entering the operating room [54]. Nowadays, VR is a valuable tool in simulation training for basic surgical skills (such as percutaneous renal access, knot tying in laparoscopic and robotic surgery) and for performing specific steps of surgical procedures (such as vesicourethral anastomosis in robotic-assisted radical prostatectomy). Additionally, these can be performed in an isolated environment or combined in a "full immersion simulation" mimicking a real-world operating room, but free of ethical dilemmas. Altogether, VR demonstrates beneficial effects in decreasing operative time and increasing technical skills, with several reports testifying the positive impact of VR training on operating room performance [9, 44, 55].

Nonetheless, there are still major barriers to its broad implementation, namely the lack of fully trained tutors and the low availability of simulators in middle to low-volume centers. Additionally, the high costs associated with set up, limit the trainees' access to training centers and the opportunities for adequate practice before entering the operating room [44, 56].

Currently, many different types of urological simulators are available, with diagnostic procedures, open, endourologic, percutaneous, laparoscopic, and robotic surgery all having validated VR simulators [57]. UroMentor® is the most validated VR system for endourologic procedures, namely cystoscopy, ureteroscopy, and percutaneous renal access. Associated costs can reach $200.000, which is not affordable for middle- and low-income countries. Regarding laparoscopic surgery, simulators are also expensive, with prices ranging from $55.000 to $100.000, but while many basic skill models have been validated, the same does not apply to procedure-specific models. Another example is the robotic-assisted surgery VR simulators. There are, until now, six robotic-assisted surgery VR simulators commercially available, with high associated costs (the less expensive, dVSS®, reaches $90.000), and still being dependent on having a da Vinci console for its use. For this reason, the associated costs are considerably higher than the previously mentioned [21, 56]. The cost-effectiveness is still largely undetermined, except for one study on RoSS®, a robotic-assisted surgery VR simulator that can be incorporated with the DaVinci console, that described operating room savings of up to $600.000, concluding that it could be a cost-effective training method [58, 59].

Notwithstanding its great value as a simulation training tool, information on its cost-effectiveness is still insufficient. Therefore, more studies addressing this issue are needed before VR can establish itself as one of the main simulation tools in Urology simulation training [56, 60].

23.3.4 Cadaveric Simulation Training

For more than 400 years, cadaveric dissection has been the primary teaching method used in undergraduate anatomy education [61]. Considering that a deep knowledge of anatomy is of paramount importance for the development of surgical skills, the use of cadaveric models has often been considered a viable complement to surgical training. However, fresh cadavers not only lack the longevity period to undertake surgical training but also carry a risk of infectious diseases, which makes them inadequate for this purpose [62]. Fresh frozen cadavers have also been used, but they do not eliminate the risk of infection and still provide limited working time [63]. On the other hand, despite providing long-term structural preservation, traditional formalin-based embalming methods used for anatomic purposes often alter the quality of human tissue in terms of color and flexibility, thus impairing proper surgical training [64]. Moreover, the use of formaldehyde is also not ideal due to the associated deleterious health effects [63].

For these reasons, alternative embalming techniques have been developed to provide realistic cadaveric models for surgical training, namely the so-called soft-fix techniques [64]. The Thiel embalming method, consisting of the intravascular infusion of a water-based preservation solution (including glycol, various salts, and low levels of formalin) over a three-day period, followed by 3 months of cadaver submersion, provides soft and flexible cadavers with almost natural colors, with adequate disinfection efficacy and minimal exposure to harmful chemicals [62]. A Multispecialty evaluation of Thiel cadavers concluded that this technique provides realistic models, with reduced odor, that is suitable for surgical simulation [64]. Long-term cadaveric preservation (6 months to more than 3 years) can be achieved by storing the cadavers in vacuumed plastic sheets in separate storage containers at 4 °C [62]. The total cost of preparing a Thiel cadaver has been estimated to be around $1200, approximately 20 times more expensive than the traditional formalin-based embalming methods [62].

More recently, Goyri-O'Neill et al. described a closed-circuit arterial perfusion technique for cadaveric embalming using an optimized solution of aliphatic alcohols [65]. With a total perfusion period of less than 1 h and without requiring subsequent cadaver submersion, this technique is considerably shorter than the Thiel embalming technique [65]. Light and scanning electron microscopy histological analysis show that this embalming technique is effective at long-term preservation (over 1 year), for cadavers stored at low temperatures (4 °C) [65]. Tissue characteristics, in terms of color, texture, and mobility have been shown to be superior to Thiel-embalmed specimens, therefore providing optimal specimens for surgical dissection [65].

Cabello et al. proposed a renal transplantation model using Thiel-embalmed cadavers, which included organ harvesting, bench surgery, and transplantation steps of the procedure [66]. A total of 28 residents, junior transplant surgeons, and faculty members participated in the study and considered the model realistic and reproducible [66]. The authors provide an estimated cost of $1300 for the reagents consumed for the injection and immersion of a single cadaver, but state that the actual cost may vary between different institutions [66].

Regarding the use of cadaveric simulation training for laparoscopic surgery, Rai et al. described a model of transperitoneal laparoscopic nephrectomy on Thiel-embalmed cadavers [67]. A total of 24 participants, grouped into experts and non-experts, evaluated the model, showing not only face, content, and construct validity but also reliability [67]. In terms of costs, the authors estimated a total of $25.000 for the infrastructure required to maintain the cadavers, around $500 for the chemicals used to embalm a single cadaver using the Thiel technique, and an individual fee of $1.400 to perform a 2-day course [67]. Huri et al. described the use of fresh-frozen cadavers to train laparoscopic nephrectomy, prostatectomy, and cystectomy, but no information was provided on the validity or cost of the model [68].

Regarding the use of cadaveric simulation training for robotic surgery, Bertolo et al. described a single session of robotic training using fresh-frozen cadavers [69]. A total of 22 residents with previous experience in robotic surgery rated the model superior to virtual reality simulators or wet-lab training and showed a significant perceived improvement in several basic surgical skills, with the supervisors considering the model effective in improving the residents' robotic skills [69]. No information on the cost of the program was provided.

Blaschko et al. described the coordinated multiple uses of fresh-frozen cadavers to optimize robotic surgical training in coordination with cardiac surgery training [70]. Seventy-two percent of participants operating on a previously used cadaver were satisfied with their training experience and did not perceive the previous use as deleterious to their training [70]. This modality of cadaveric surgical training reduced the cost from $2.250 to $1.375 per use [70].

Regarding the use of cadaveric simulation training for endoscopic procedures, Bele et al. described the use of Thiel-embalmed cadavers to train upper and lower urinary tract endoscopy [71]. A total of 12 experienced urologists considered the model adequate to train in urethroscopy and ureteroscopy, but not to perform cystoscopy, due to the lack of adequate color characteristics of the bladder mucosa [71]. The authors report a cost of $1.200 per cadaver but consider that this constraint can be minimized by using the same cadaver to train multiple procedures [71].

Mains et al. describe a two-day masterclass on flexible ureterorenoscopy using Thiel-embalmed cadavers [72]. A total of five participants and three faculty members considered the quality of vision and irrigation in the upper urinary tract as high, with most of the overall quality of the tissues as high or excellent, but reported the ureter to be more prone to trauma than in the live patient [72].

Lentz et al. describe laboratory training on implant surgery using cadaveric models [86]. At an individual cost of $1.483, a total of 31 residents rotated through nine 25-min stations, covering penile prosthesis, male sling, and artificial urinary sphincter placement procedures, with participants showing a significant improvement in procedural knowledge and surgical confidence, mainly the ones with less previous experience in the procedures [86].

Despite the clear benefits of cadaveric simulation training, it is not devoid of limitations, not only in terms of costs and of the required infrastructure to prepare and store the cadavers, but also in terms of ethical, cultural, or religious issues.

23.4 Non-technical Skills Training in Urology

Over the past few years, the value of non-technical skills has been widely recognized in several areas of healthcare provision. In fact, in surgery, suboptimal non-technical skills have been found to be responsible for more adverse events than operating technique faults [73]. However, traditional surgical training during urology residency programs does not seem to be addressing the importance of non-technical skills training adequately, considering that an assessment of situational awareness, decision-making, communication, teamwork, and leadership on a simulated ward round proved that residents' performance could be improved [74].

Even though there is still no evidence that non-technical skills training of operating theater staff improves patient outcomes, there seems to be a strong correlation between technical and non-technical performance, irrespective of the training received [42, 45, 75].

A systematic review of current non-technical skills training modalities identified several articles describing different types of training methods and proposed an integrated and progressive framework for non-technical skills training in surgery, based on didactic and simulation-based teaching, full immersion/distributed simulation (low-fidelity simulation), high-fidelity operating room simulation, and crisis resource management. Furthermore, the same review also recommends the use of validated assessment scales in non-technical skills training, both for individuals (NOTSS) and teams (NOTECHS) [76].

Although it might be difficult to evaluate the cost of providing a non-technical skills training curriculum, there is some evidence that low-fidelity simulation might be more cost-effective than high-fidelity operating room simulation [77].

23.5 Comprehensive Approach to Simulation-Based Surgical Training in Urology

Over the past decades, due to the limitations of traditional surgical training, several simulation courses have been developed. Most courses are procedure-specific and usually have a duration of some hours to 2 days. However, considering the complexity of urological training and the multitude of surgical procedures in which urologists must gain proficiency, there was a need to develop a comprehensive approach to simulation training.

One such approach consisted of the development of intensive simulation-based courses encompassing the training of multiple skills. Considering that these courses usually have a modular organization, comprising several different modules aimed at specific skills, they can therefore be designed to provide training to residents at the beginning of their residencies, when they are expected to change their role, or at the end of their surgical training [29, 78].

Overall, with a cost that can reach 1.800€ per trainee (depending on the duration of the course, the number of trainees, and the complexity of the skills to train), these courses have been proven not only to improve trainee confidence but also technical and non-technical skills in different domains [80–82].

The other approach consisted of the development of integrated simulation-based training curricula, comprising a series of validated training and assessment levels of progressive complexity, in order to standardize surgical training in a given area. The European Association of Urology and the European School of Urology have developed several integrated training curricula, namely in laparoscopy, endoscopy, and robotics [83–85]. Due to the success of these programs, the European School of Urology is developing an innovative training program for urology residents in Europe, which integrates the full spectrum of simulation-based training in urology, in order to allow stepwise training from basic to advanced skills in endoscopic stone treatment, transurethral and laparoscopic urological surgery, with the aim of improving and standardizing European urological training [85]. Although the costs associated with such a program are difficult to ascertain in advance, they will undoubtedly be considerable. In fact, an international scholarship of more than 380.000€ was approved to support the implementation of the program in five European countries [85].

23.6 Conclusions

Simulation-based surgical training has been considered the solution to many of the challenges faced by traditional surgical training. Over the past decades, the evidence on the benefits of simulation-based surgical training has been growing, namely concerning technical skills training modalities, like dry-lab, wet-lab, virtual

Table 23.1 Characteristics of technical skills simulation training modalities

	Fidelity	Reproducibility	Cost	Ethical dilemmas	Proposed recommendation
Dry-lab simulation training	Low	High	Low	None	Basic training (basic skills) and assessment
Wet-lab simulation training	Medium	Moderate	Low/ medium	Possible	Intermediate training (complex skills/steps of procedures)
Virtual reality simulation training	Variable	High	Medium/ high	None	Intermediate training (complex skills/steps of procedures) and assessment
Cadaveric simulation training	High	Moderate	Medium/ high	Possible	Advanced training (complete procedures)

reality, and cadaveric simulation training. However, given the multitude of evidence on the subject, it is important to objectively analyze not only the benefits but also the limitations of these surgical training options, including their cost, in order to adequately include them in a broader approach to surgical training (Table 23.1).

Key Points

- Traditional surgical training faces considerable challenges that may compromise the adequate training of competent and autonomous surgeons.
- Simulation-based surgical training has been trying to surpass many of the downsides of traditional surgical training.
- Dry-lab simulation training has high reproducibility and low cost, and is therefore adequate for basic training and assessment.
- Wet-lab surgical training has higher fidelity compared to dry-lab, without being associated with high costs, and is therefore adequate for intermediate training.
- Virtual reality simulation training has high reproducibility and no ethical dilemmas and is therefore adequate for intermediate training and assessment.
- Cadaveric simulation training has high-fidelity but is associated with high costs and may pose some ethical dilemmas, and is therefore adequate for advanced training.
- Non-technical skills simulation training may be useful to optimize surgical performance, with low-fidelity simulation eventually being more cost effective than high-fidelity operating room simulation.
- A comprehensive approach to simulation-based surgical training might be the best option to optimize modern surgical training in urology.

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Chapter 24
Standardization of Training

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24.1 Introduction

24.1.1 Background

Training is defined as a methodical activity of physical, psychological, and tactical preparation for the execution of a procedure. The target of training aims to obtain maximum performance, with an increase in dexterity, strength, control, and resistance to fatigue. The purpose of a training program is to be able to carry out a specific activity continuously, so as not to lose practice and ease in certain mental and manual operations.

Surgical training has the specific goal of improving capability, capacity, efficiency, and performance. It also represents a key factor in optimizing clinical outcomes. Well-trained surgeons perform higher quality procedures, resulting in increased patient safety and reduced operative costs. On the other hand, the training itself requires a time-consuming learning curve and can be afflicted with a higher number of adverse events.

In the last 30 years, the development of new technologies such as optical fibers and sophisticated laparoscopic surgical equipment led minimal invasive surgery (MIS) to take over as the gold standard in surgery, due to some clear benefits:

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reduced length of hospital stay, reduced post-operative pain, less noticeable scars, faster healing, and overall quicker recovery for daily activity. Nevertheless, not all that glitters is gold; the loss of direct vision of the structures, highly degraded tactile feedback, and different behavior of instruments handling skills, known as the fulcrum effect, stressed novel laparoscopic surgeons with a fundamental visual-proprioceptive conflict, burdening surgical outcomes.

The advent of robot-assisted surgery has overcome some of the traditional laparoscopic limitations: 3-D magnified vision, articulating wrists, lack of hand tremor and surgeon comfort have contributed to the exponential growth of the robotic approach in several specialties, revolutionizing the world of MIS and advocating for new kinds of surgical training. There are, however, no agreed guidelines that define the best way to train a novice robotic surgeon, in contrast to laparoscopic and open surgery training protocols [1].

Since robotic surgery training standards have not been set yet, competency verification varies highly between institutions. A common way to assign qualifications to perform a procedure is considered by the number of cases performed by the surgeon. In spite of this, little evidence shows that performing a predetermined number of cases leads to an acceptable level of performance in robotic surgery [2]. Authors describe a large heterogeneity of data for the achievement of the learning curve, as the number of cases needed to assess plateau performance ranges widely [3]. A study by Lee et al. suggests that the acquisition process of robotic surgery competence should encompass the demonstration of proficiency and safety in executing basic robotic skills and procedural tasks, instead of being based on the number of completed cases [4].

Well-performed training is an essential factor in patient safety. Several studies report a higher complication rate related to MIS trainees, particularly at the start of their learning curve [5, 6].

Surgeons without specific laparoscopic fellowship training converts more operations to open surgery than those with dedicated training [7].

Nevertheless, standardized training for robotic surgery should be recommended regardless of trainee experience; considering that the surgical outcomes of senior surgeons with high experience in open surgery and robot-assisted radical prostatectomy (RALP) become comparable to those obtained with a traditional open surgery only after 150 procedures [8]. Furthermore, costs associated with robotic surgery training in the operative room (OR) are substantial and must therefore be taken into consideration while developing new training programs.

Training novel surgeons directly on the patient in the OR adds considerable operative time to the length of the procedure, and thus increases the associated costs [9]. In the USA, the average cost of OR per minute stands at 36–37 dollars, meaning that services performed in the OR account for almost one-third of the total healthcare spending. The cost of robot prostatectomy training has been estimated by Steinberg et al., who built a theoretical model that calculated the cost of operative time for the learning curve. They assessed a range from a minimum of 24 cases, accounting for $95,000, to a maximum of 360 cases, accounting for $1.3 million. This data explains the higher increase in economic growth of nonteaching hospitals when compared to teaching hospitals in the USA between 2004 and 2015 [10, 11]. For all these reasons, training novices exclusively inside the OR environment does not make good economic sense. A standardized, validated, metrics-based protocol of robotic surgery training for different specific procedures is therefore advocated.

24.2 Standardized Training Cornerstones

Standardization of training aims to bring us back an unitary and exemplary model, based on recognized and shared criteria. It should be uniform and reproducible. As robot-assisted surgery is rapidly expanding, validated, evidence-based robotic curricula will be a crucial step in the global standardization of training for surgeons, involved in robotic surgical procedures [12].

The basis of a standardized training program should include the recording of trainees' performances and focus on trainers selection and assessment skills to guarantee high-level training curricula [13].

To achieve this, in 2019, a panel of 32 international experts convened and discussed guidance on an optimized "train-the-trainer" (TTT) structured educational program for surgical trainers, in which delegates learn a standardized approach for training candidates in skill acquisition. There was 100% agreement on the need for a standardized TTT course in robotic surgery [14]. Besides that it was stated that expert surgeons may not necessarily be expert trainers. The trainer should be a person with good communication skills and with a good grasp of the instruction language, with adaptable and flexible skills, and have a friendly disposition. Trainer competency must be verified. Excellent surgical trainers are likely to be excellent clinicians in their daily activities [15]. The goal of the trainer should be the completion by the trainee of a specific task in a limited amount of time, making a minimum number of errors in order to reach a proficiency benchmark.

The experts agreed that the ideal training should be objective, transparent, fair and have a proficiency-based evaluation.

Proficiency-based progression (PBP) is a training methodology where training a skill or task is repeated, until a defined benchmark of this skill is consistently met. Only then is the trainee allowed to progress to the next difficulty level [16].

Prospective, randomized studies on PBP showed that metrics-based simulation training, derived from and benchmarked on experienced and proficient surgeons, produces a superior surgical skill set in comparison to traditional training approaches, with an additional effect on shortening the learning curve [17].

Therefore, standardization of training should involve a PBP-based curriculum that allows the trainee to acquire more advanced skills in a graduated fashion. This structured curriculum should include preclinical and clinical features to facilitate the proper adoption and application of robot-assisted tasks [4].

A structured training curriculum should include theoretical training (e-learning, case observation), preclinical simulation-based training (virtual reality simulation, dry and wet lab), clinical modular training, and a final proficiency-based assessment.

24.2.1 Theoretical Training

Historically, surgical training was built on the solid roots of the Halstedian apprenticeship [18].

Hundreds of junior surgeons spent thousands of hours alongside their mentors in order to observe their gestures.

Observation allows the trainee to comprehend the mentor's gestures that subsequently can be reproduced in a simulated setting. Observing experts performance of surgical tasks, and then imitating them through simulation, is a basic principle that every trainee will encounter during their learning curve. These are the first steps of a standardized training program.

Besides attending live cases in the O.R., which continues to have a strong impact on trainees, several platforms for e-learning have been created to facilitate access to surgical procedure observation and detailed technical skills with explanations. E-learning, and more generally, video training, is an essential tool to acquire good theoretical understanding and improve technical performance. Usually, this consists of videos and dedicated online surgical channels, easily available after minimal registration, which allows the observer to repeatedly watch surgery performed by an expert. These videos may be commented on by the operator during live presentations, or stored in a virtual library for educational purposes. E-learning platforms can also offer assessments which evaluate the trainee, and produce a certificate of attendance thus increasing the training's quality.

Authors have shown how e-learning can have higher or equal effectiveness compared with both no intervention and non-e-learning interventions [19]. However, the use of these novel educational approaches is not straightforward, and requires learning new methods of digital learning assessment and a re-evaluation of educational roles [20].

24.2.2 Preclinical Simulation-Based Training

Learning what to do and what not to do is the first crucial step in any standardized training program. The second step is simulation of surgical technical performance. For this purpose, several models exist to help improve technical skills and defining different protocols for preclinical simulation-based training. We can divide these into bench-top models, computer-generated experiences such as online simulations and virtual reality (VR) simulations which allow the trainee to reproduce parts of a specific surgical task.

Virtual reality simulators represent an alternative strategy in the acquisition of surgical skills and are particularly useful at the start of the learning curve. The ability of VR simulation training to improve real-world tasks has been described, especially regarding the reduction of procedural errors [21]. Although VR simulators have some clear advantages, such as the reduced risk for patients and their immediate re-usability, most of them lack technical fidelity and haptic feedback. Sometime, their virtually reproduced gestures are not realistic when compared to the real movements of the trainee. A systematic review published in 2016, reported that it is not clear which exercises and metrics are most effective in distinguishing different levels of experience on the da Vinci robot. Moreover, controversial pieces of evidence on skills transfer from simulation to clinical surgery on real patients has been reported [22].

These limitations of physics-based emulations can be overcome when the simulation is applied to real templates, such as synthetic or biologic animal-based models [23]. For this reason, we can classify different preclinical simulation-based training as dry-lab or wet-lab. A dry-lab consists of the reproduction of a specific task that does not involve any biological tissue. The activities that take place in a dry-lab usually preceed wet-lab training. Since biological liquids are not involved, environmental regulations are less stringent. The main benefits of a dry-lab include reliability, low cost, and easy access to equipment. A limitation is the lower face validity in simulating a realistic surgical setting, making it less attractive for trainees [24].

A wet-lab is one where drugs, chemicals, and other types of biological products can be analyzed and tested. Wet-lab training can be further sub-divided into *in vivo* modules, where living anesthetized animals are used, and *ex vivo* modules, where animal tissues serve as the base of the simulation-based training method. The advantages of wet-labs are the higher fidelity experience the trainee has in terms of instruments' handling and haptic feedback from the tissues. The consistency and fragility of animal models such as chickens or pigs are very similar to those of a live patient, representing a challenge for the trainee. They are good models for the trainer to ascertain the performance level of the trainee. However, animal tissues can be quite expensive, require special and dedicated facilities to preserve their integrity and require strict hygienic measures. Furthermore, these types of animal models remain fresh for a short time, and can only be used a limited number of times, which makes their regular use complex.

Recently, the use of these preclinical models has been investigated for metrics-based simulation training.

Metrics represent an operational definition of an entity, object, location, etc., that unambiguously characterizes fundamental aspects of a procedure or skill performance. Basically, metrics compose the performance units for simulation proficiency-based training [25]. When trainees receive metric-based feedback on their performance, the learning experience is optimized. Trainees should receive detailed feedback on errors made during the procedure, in order to understand what to do correctly and how to improve performance in the subsequent trials. This approach is the base of the deliberate practice concept.

Deliberate practice is a focused approach to skill training, highly structured and geared to achieve a well-defined goal [26]. Combining deliberate practice and metrics improves the acquisition of a specific skill, allowing the trainee to minimize the number of errors and to speed up performance benchmark achievement. The trainee should be able to perform the task until they reach the performance benchmark. This metrics-based approach produces a homogeneous skill set in trainees, and can be applied to any type or level of training [25]. These preclinical simulation-based models significantly improve surgical performance when objective metrics are applied [27]. Once the benchmark is reached on the preclinical models, the trainee can start their learning in the OR during a clinical modular training program.

24.2.3 *Clinical Modular Training*

Each surgical procedure consists of multiple steps, which involves different tasks, such as cutting, dissection, suturing, and therefore requires specific basic skills training.

Research of motor learning theory shows that a task's complexity (number of movement segments) and organization (temporal relationship between the composite movement segments) defines the most effective way to practice it, in order to create an optimized modular training [28].

Subjects who received simulation-based training on specific isolated skills showed superior overall intraoperative performance [29].

A modular-based clinical training promotes persistent and rapidly acquired surgical skills, in the short- and long-term, when compared with standard training [30]. Complex tasks are best split up and trained as—separate tasks because training parts of the whole procedure helps the trainee to quickly assimilate the necessary skills.

Moreover, part-task simulation-based training offers a more cost-effective approach compared with wholetask training [31]. Progressive, proficiency-based training of tasks through different surgical steps with increasing difficulty represents a better approach to train complex procedures.

24.3 Training Curricula

Research indicates that standardization of training should include simulation and modular training, integrated into a structured curriculum. The need for a multi-step curriculum for robotic training has been recognized by an international expert panel of surgeons, engineers, and medical educators [32].

Each curriculum should include technical console skills and non-technical skills for patient selection, pre-operative preparation, communication effectiveness, and complication management.

To date, several robotic surgery training curricula have been developed and we can classify them into validated and unvalidated robotic curricula.

The majority of training consists of short-term training sessions and is focused on preclinical simulation-based programs (virtual reality, dry lab, wet lab). The absence of clinical modular training guarantees better accessibility but represents a hurdle in the development of non-technical skills. On the other hand, a few curricula are composed as a structured fellowship style program with pre-clinical and clinical modular training. In this section, we will provide an overview of the available robotic surgical training curricula with their main features.

24.3.1 Validated Curricula in Robotic Surgery

The first-ever validated training curriculum on robotic surgery was developed in 2012 by the University of Texas Southwestern Medical Center [33]. This curriculum was a multidisciplinary, comprehensive, proficiency-based training composed of three features: a basic online tutorial on robotic surgery, followed by an interactive hands-on training session on the standard da Vinci system, and the execution of nine inanimate exercises of increasing difficulty. Trainees were required to self-practice for 2 months on a pelvic trainer and evaluation was performed at the end using the metrics of a pre-existing laparoscopic validated curriculum, known as "Fundamentals of Laparoscopic Surgery" (FLS).

In 2013, the University of Toronto developed the "Basic Skills Training Curriculum" (BSTC) [34].

The BSTC is characterized by a 4-week training period, which is comprised of a theoretical part with didactic lectures and online modules, and a practical course on basic skills exercises on the da Vinci Surgical Simulator. The evaluation of the trainees was performed by the built-in assessment tool of the simulator. In these first two curricula, wet lab procedures or clinical modular training is not included thus limiting the impact on the overall learning curve experience.

In the same year, an integration of FLS on robotic basic skills was published, the Fundamental Skills of Robotic Surgery (FSRS), showing a significant improvement in basic skills by trainees [35]. This protocol focussed on 3 tasks: ball placement, suture pass, and fourth arm manipulation. It consists of a simulation-based training program, based on 4 different modules (orientation, motor skills, basic and intermediate surgical skills) with a series of 16 tasks. Evaluations of FSRS were also done through laparoscopic-based FLS metrics.

In 2014, the European Association of Urology Robotic Urology Section (ERUS) developed the first structured and validated curriculum on a specific surgical procedure, robot-assisted radical prostatectomy [36].

The ERUS curriculum consists of a graded, omnicomprehensive, modulated program, providing all-around knowledge of the procedure. Trainees first study an e-learning module, where they become familiar with basic device use and surgical technique. After the theoretical part, trainees start a hands-on training workshop in the dry lab, to learn the device's visual-spatial orientation and improve their understanding of the robot's main features such as camera movements, clutching of the instruments, EndoWrist manipulation, etc. The subsequent module consists of a 1-week intensive wet lab, where trainees practice on animals, canine cadavers, or live porcine models.

The training also includes 6-months of clinical modular training under expert surgeon supervision in the OR. This ensures the engagement of the trainee in surgical steps with increasing complexity levels while developing deep knowledge on technical and non-technical skills.

At the end of the course, the trainee performs a complete RARP procedure, which is evaluated by an expert trainer using a validated assessment [2]. In order to increase access to the complete course for less experienced trainees, the course was extended from 3 to 6-months. This longer training period allows the trainee to better distribute training sessions over time, resulting in an increased surgical exposure and a higher possibility of long-term surgical skills retention when compared to shorter intensive courses [37].

One year later, in 2015, Valdis et al. published a randomized trial about the first validation of a novel virtual reality training curriculum for robotic cardiac surgery, demonstrating that simulation-based training can significantly improve the efficiency and learning quality in robotic cardiac surgery [38].

In 2018, the Society of European Robotic Gynecological Surgery (SERGS) outlined a Pilot Curriculum for standardized education in robot-assisted laparoscopic gynecological surgery [39].

This curriculum consisted of a multi-modular composed program. The exercises reproduced complex interventions such as hysterectomy and pelvic lymphadenectomy. Similar to the ERUS curriculum, after the e-learning phase, there was a practical part involving intensive training on simulators, dry labs, and wet labs, and a final clinical training in the OR. As a finale evaluation, the trainees sent a logbook and a video of a complete procedure which was evaluated by an experienced surgeon (in order to receive a certification of attendance).

Following the footsteps of the RARP curriculum, ERUS published in 2019 the latest validated curriculum available for robotic surgery, on another specific procedure, robot-assisted partial nephrectomy (RAPN) [40].

Interestingly, clinical modular training was based on the division of a complete RAPN procedure in ten separated steps, which divides the procedure into reproducible tasks.

In detail, five progressive modules merge ten specific steps, ordered to an increasing level of skill complexity. A surgical case video recording with a blinded evaluation by an expert surgeon marks the final assessment for the trainee.

24.3.2 Unvalidated Curricula in Robotic Surgery

To date, several unvalidated curricula on robotic surgery training have been described.

The majority consists of simulation-based training focused on basic robotic skills and do not apply to specific surgical procedures. Conversely, two training curricula have been developed that are dedicated to urology. The British Association of Urological Surgeons (BAUS) developed a training curriculum aimed to train four specific urological procedures: RARP, RAPN, robot-assisted radical cystectomy (RARC), and pyeloplasty [41].

Each of these procedures has a modular training involving e-learning, observation, preclinical simulation, a mentorship period, and practice in the OR. However, validation of these curricula is necessary to allow for global application. The other urological dedicated unvalidated program is the ERUS RARC structured modular curriculum [42]. As with the other ERUS courses, ERUS RARC aims to train technical and non-technical skills in a well-defined multiple steps program. Still, clinical implementation is required for validation.

24.3.3 Standardized Scoring Systems for Robotic Skills Evaluation

Standardized scoring systems are based on the application of rigorous rules or criteria, previously defined or agreed upon, and therefore allow an objective evaluation. These systems guarantee the reproducibility of the correction, and eliminate the contribution, of the subjective component of the evaluator.

Each structured training curricula should refer to a standardized assessment tool; these tools can be related to fundamental robotic skills or specific surgical procedures.

To date, a few basic skills scoring systems have been described:

- Global Evaluative Assessment of Robotic Skills (GEARS) is a scoring system which evaluates six fundamental domains: depth perception, bimanual dexterity, efficiency, force sensitivity, autonomy, robotic control. These domains derive from a previous laparoscopic assessment tool and have been adapted to robotic surgery. GEARS has been widely investigated as a valid and reliable skills assessment to evaluate intraoperative robotic skills and has an impact on clinical outcomes when related to RARP [36, 43].
- Robotic Objective Structured Assessment of Technical Skills (ROSATS) is a basic robotic skill set developed for abdominal surgery on a synthetic model. ROSATS evaluates five inanimate exercises regarding depth perception, accuracy, force and tissue handling, dexterity, efficiency. It is a useful tool to distinguish between the performance levels of trainees, but requires a subjective evaluation [44].
- Structured Assessment of Robotic Microsurgery Skills (SARMS) is an assessment tool developed together with 10 plastic surgeons in order to evaluate microsurgical skills. SARMS includes three parameters to assess conventional microsurgical skills, dexterity, visuospatial ability, and operative flow. The robotic skills incorporate five additional parameters, including camera movement, depth perception, wrist articulation, atraumatic tissue handling, and atraumatic needle handling. Each parameter is scored from 1 to 5, with 1 being the worst and 5 being the best. The overall performance and overall skill level are assessed independently [45].

- Assessment of robotic console skills (ARCS) is a global rating scale on multiple console domains, some of them not evaluated previously, including bimanual wrist manipulation, camera control, master clutching to manage hand position, use of third instrument arm, activating energy sources, appropriate depth perception, and awareness of forces applied by instruments [46]. This study showed that learning curves for some console skills plateau faster than others. Therefore, ARCS is a useful tool to evaluate distinct console skills.
- Generic dedicated scoring criteria (GDSC) is a tool aimed at evaluating videos for the procedural steps of RARP, created for the ERUS RARP curriculum [36]. The assessment is performed by blinded, expert surgeons and investigates parameters such as correct use of instruments, tissue handling, and procedural errors.
- ORSI basic skills course (BSC) represent the first step of a structured PBP program aimed at creating a proficient robotic surgeon. BSC focuses on the acquisition of basic surgical skills, such as suturing, knotting, coagulating, and dissecting, objectively evaluated with validated performance metrics [47]. Consensus on defined performance metrics (procedure steps, errors, and critical errors) was achieved by a panel of international experts after a Delphi process, demonstrating the face and content validity of the training. Each basic skills task is preceded by pre-course learning, and only attendees who have reached the benchmark level are permitted to attend the hands-on courses.

Recently, procedure-specific scoring systems have been developed, with the purpose of evaluating both the acquisition of technical skills and mastery of the procedure, in order to ensure patient safety and surgeon autonomy for a specific intervention. Nevertheless, there is a lack of available data on clinical outcomes related to these scoring systems [43]. Among these tools we mention:

- The Objective Assessment of Intra-Operative Robotic Skills for RARP is a metrics-based scoring system for a specific procedure, developed by the ERUS scientific and educational metrics working group initiative [48]. RARP phases, steps, errors, and critical errors were discussed and validated by a panel of 19 experts after a modified Delphi process, in order to implement a full standardized PBP training pathway dedicated to RARP.
- High-level consensus on the RARP metrics made it possible to distinguish between the surgical performances of expert and novice surgeons. The presence of objective, reliable, and valid performance metrics represents the key to effective and quality assured surgical training.
- The RARP Assessment Score is a structured modular assessment tool created to distinguish critical procedural steps and evaluate technical tasks acquisition during the RARP learning curve [49].
- Robotic Anastomosis Competence Evaluation (RACE) allows the evaluation of surgical competence regarding a specific critical task of RARP, the urethravesical anastomosis [50].
- Prostatectomy Assessment and Competence Evaluation (PACE) is an objective and procedure-specific tool to assess the quality of RARP [51]. PACE has been developed after 3 rounds of consensus using the Delphi methodology. Seven key

domains that objectively measure surgical performance, differentiate levels of expertise and provide structured feedback to customize training and surgical quality improvement.

- Scoring for Partial Nephrectomy (SPAN) is a structured scoring system for RAPN that can provide objective feedback for the assessment of technical skills. SPAN has been developed by a panel of 10 expert surgeons and validated with the Delphi method. Six procedural domains have been recognized: exposure of the kidney, identification and dissection of the ureter and gonadal vessels, dissection of the hilum, tumor localization and exposure, clamping and tumor resection, and renorrhaphy [52].
- The RAPN Assessment Score is a system aimed to identify the most hazardous steps of RAPN. This tool fragments the procedure into 26 steps, merged into 6 phases, and was designed as a pillar for trainee assessment and evaluation of training programs. Further validation and implementation of the RAPN learning curve is advocated in the future [53].
- Pelvic Lymphadenectomy Appropriateness and Completion Evaluation (PLACE) is a structured intraoperative scoring system to measure and quantify pelvic lymph node dissection (PLND) for quality control after RARC [54]. Videos of PLND were assessed by 11 experts and a nodal template was structured into three zones, for each zone a lymph node clearance score has been defined. PLACE aim is to give an intraoperative quality measure for standardizing performance and help facilitate training.
- Cystectomy Assessment and Surgical Evaluation (CASE) is a validated, structured, procedure-specific tool for objective evaluation of surgical performance during RARC [55]. Domains of the CASE include PLND, development of the peri-ureteral space, lateral pelvic space, anterior rectal space, control of the vascular pedicle, anterior vesical space, control of the dorsal venous complex, and apical dissection. Scoring of these tasks may help differentiate novice from expert performances.

24.4 Future Perspectives

Structured modular training models, based on theoretical, preclinical, and clinical phases, appear to be the most effective learning tool for trainees. Standardization of training, through the accreditation and certification of well-defined training curricula, should be implemented in the earliest part of a surgical career as a quality mark.

Proficiency-based progression training, based on validated and well-defined metrics, allows an objective evaluation of the trainee's performance. The magnitude of the training benefit of PBP training appears to be the same in surgery, cardiology, and procedure-based medicine [56].

Application of PBP training has been shown to improve trainees' skillsets by 40–60% when compared to the level reached using conventional or traditional training. Therefore, its application in robotic surgery is recommended [57].

Furthermore, the development of novel technologies for rapid multimedia data transmission opens the opportunity of implementing training models through a telementoring system, allowing for a greater number of trainees to have access to a high-quality certified training experience.

24.5 Summary

As robot-assisted surgery is rapidly expanding, validated, evidence-based robotic curricula will be crucial in the global standardization of training and will represent a quality certification for surgeons involved in robotic surgical procedures. Standardized and validated training programs are needed to optimize patient safety, clinical outcomes, and cost management. e-learning, dry lab, wet lab, clinical training under supervision, and proficiency-based training are the key steps of a complete training curriculum. Although several training curricula have been developed, few of them include clinical modular training. Modular clinical training promotes consistent and rapidly acquired surgical skills. Structured curricula aim development of technical and non-technical skills to provide novel surgeons with the all-around preparation which is needed for the OR.

Key Points

- Although robot-assisted surgery is rapidly expanding, there is a lack of consensus and no mention in the guidelines on the best way to train a novice robotic surgeon.
- Standardized and validated training programs are needed to optimize patient safety, clinical outcomes, and cost management.
- A structured training curriculum should include: theoretical training (e-learning, case observation), preclinical simulation-based training (virtual reality simulation, dry and wet lab), clinical modular training, and a final objective assessment.
- Proficiency-based progression (PBP) training, based on validated and well-defined metrics, allows an objective evaluation of the trainee's performance, producing superior surgical skill preparation in comparison to traditional training.
- Several training curricula have been described; however, most of them focus on preclinical simulation-based programs and lack a structured fellowship style program with clinical modular training.
- Standardization of training should be encouraged with the implementation of a structured PBP-based curriculum that allows the trainee to acquire advanced skills in a graduated fashion.

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Chapter 25
The Role of Immersive Technologies in Urological Simulation

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25.1 Introduction

Immersive technologies encompass any simulation modality that uses technology to emulate and supplement aspects of the physical environment. The degree of immersion is mapped on a "reality-virtuality" continuum depending on the balance between virtual and real-life interactions and is abbreviated as their "X-reality (XR)" identity [1] (Fig. 25.1). The physical world is at one end of the spectrum, and the virtual world, or Virtual reality (VR) systems is at the other. VR simulators are completely immersive and depend entirely on computer-aided design to deliver the training experience. Partly immersive technologies, such as augmented reality (AR) and mixed-reality (MR) are defined by the fact that users can still interact and participate in the physical world. AR allows the user to superimpose a virtual element into their field of view via a tablet or head-mounted display, while still being able to fully interact with and visualize their real-life surroundings [2]. Prominent commercials of such applications are the Microsoft HoloLens and Google Glass, where users interact with virtual holographic content via gestures. Mixed-reality (MR) simulation provides feedback between digital and physical components in a simulation experience. For example, in vascular surgery, it is possible to use real instruments with mechanosensor sensitivity to provide a pressure feedback sensitivity report [3].

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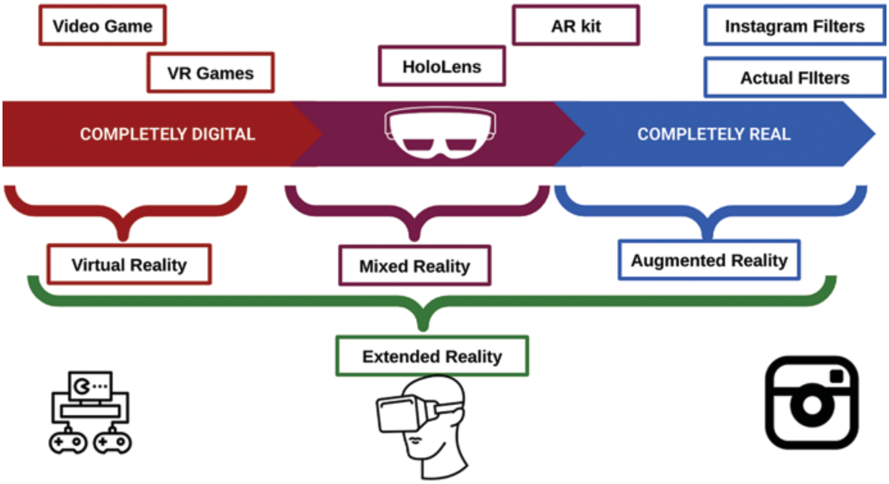

Fig. 25.1 Schematic depicting the reality-virtuality continuum

25.2 Origins of Immersive Technology in Simulation-Based Training

Immersive technologies and computer-aided simulation were originally pioneered for training in the aviation industry. There has been a long-standing comparison between surgeons and pilots in terms of the necessity for novice excellence and the defining skill of being able to exercise situational judgment in complex scenarios, managing multiple confounders, in life-or-death decisions [4]. In studies exploring the effectiveness of simulation modalities on pilots, it was found that simulators with the greatest impact are not those which impart procedural knowledge, but the requisite non-technical skills for the profession, such as adaptability and pragmatism [5]. This makes an advanced level of competence attainable at a much earlier stage than previously possible [6]. Such studies formed an evidence base, supporting the use of XR immersive simulators for formal professional training and sparked interest in the use of such principles and technologies in medical training [7].

A hallmark study testifying the effectiveness of simulation in surgical training and reducing the preventable complications attributed to errors in correctly navigating anatomy, is that of the Southern Surgeon's Club [8]. This study was among the first to introduce the concept of "learning curve" within surgery, denoting how the highest error rates and complication rates are found in the earliest part of the curve. Specifically, the study noted that novice surgeons had a 1.7% probability of causing bile duct injury, which was reduced to 0.17% by the tenth attempt. Extrapolating the curve, the authors found that by the fiftieth attempt, there was an acceptable level of safety. This study was the first to demonstrate what we now know intuitively: the early part of this learning curve should take place outside of the clinical environment so as to not compromise patient safety. It is becoming clear that the historic use of logbook-based clerking of training hours as metrics for performance is of limited value. In addition, the high cost of operating theater hire means it is far more costly to have trainees present in a procedure, learning skills that they could have learnt in simulation. This advocates an omni-learning approach, wherein technical and non-technical skills can be practiced on demand, using a spectrum of modalities and at all possible levels.

Since then, several factors have accelerated the integration of immersive technology into surgical training. Following the introduction of the European Working Time Directive (EWTD), the ability of healthcare trusts to deliver services and teaching simultaneously became compromised. This resulted in the floundering of the presupposed "modern apprenticeship" paradigm that previously dominated surgical training, giving rise to omni-learning or "point-of-need learning" instead. The need for novel evidence-based educational techniques became apparent after professional satisfaction and evaluation surveys demonstrated low trainee satisfaction was with existing curricula, and the gross imbalance between service commitments and training opportunities. This imbalance not only impacts objective performance standards, but also has negative corollaries for the mental and physical health of surgical trainees, also known as the "non-monetary costs" of surgical training [9]. This leads to higher drop-out rates in surgery than for any other specialty and acts as a deterrent for prospective surgeons from joining the profession, leading to issues of understaffing [10]. Furthermore, two landmark inquiries into the nature of surgical training, the Collins report and the Temple report, found that the vast majority of surgical trainees felt they were placed in clinical situations where they were expected to act beyond their competence [11, 12]. These challenges are set against a backdrop of heightened medico-legal awareness, auditing, and patient health literacy. This leaves little room for errors, surgical near-misses, and never events. Cumulatively, these issues highlight a need for a safe and reliable alternative to experiential learning. This must accommodate the training needs of both novices and seasoned surgeons, who are required to learn new competencies, assimilate with new technologies, or recertify [13].

Most recently, the COVID-19 pandemic has been catalytic in transforming clinical practice and service delivery. As part of the crisis management approach, non-essential and elective surgery was postponed and later consultant-led with trainees absent. Beyond clinical placements, university education was suspended, leading to further challenges in surgical training and requiring a valid, accurate, and reliable substitute to clinical experience [14]. Navigating this unforeseen event required adaptability and creativity. At the core of this approach was the "virtual revolution"; a seismic shift in attitudes and practices regarding virtual technology, viewing it as a mainstay solution rather than as a futuristic novelty [15, 16].

25.3 Validation and Appraisal of Immersive Technologies

Immersive technologies are often generated using gaming software platforms, generating an interactive product with an analogous motivation to exceed personal achievements in terms of precision, accuracy, and duration. In the context of adaptive learning theory, this translates to an accelerated learning curve and increased learner engagement [17]. Nevertheless, XR technologies can be used for formal assessment, certification, and performance appraisal once there is a solid evidence-base demonstrating their validity and educational effectiveness. Four levels of validity may be demonstrated, including face (the extent to which the expert and non-expert users report that the technology meets its stated aims and objectives), content (expert-approved), construct (ability of the tool to distinguish between experts and trainees), and predictive validity (the ability to predict a learner's performance at a later date) [18]. The final category is particularly important when considering the appraisal of surgical skills. As for certification, it is important to demonstrate that the skills acquired in simulation can translate well in real-life contexts. The Kirkpatrick Model is a four-level system used for evaluating the educational influence of training platforms. This is ranked on a tiered, hierarchical taxonomy; reaction (level 1), learning (level 2), behavior (level 3), and results (level 4).

Surgical performance metrics are typically divided into technical skills and non-technical skills. A general proforma for evaluating technical skills is the Objective Structured Assessment of Technical Skills (OSATS), which can be used to appraise a trainee's performance in a wide range of clinical competencies. Procedure-specific checklists, such as the Global Evaluative Assessment of Robotic Skills (GEARS) for robotic surgery and the Fundamentals of Laparoscopic Surgery (FLS), are two validated assessment methods for technical skills. These can be integrated into curricula using XR systems to generate a performance report, or be used in conjunction with videotaping of trainee performance on XR simulators and reviewed with clinical supervisors as part of an educational review. The Non-Technical Skills for Surgeons (NOTSS) take into consideration the situational awareness, decision-making, communication & teamwork, and leadership demonstrated by a trainee during a task. While these competencies have not received the same amount of attention as technical skills assessment, their significance in clinical and surgical practice is becoming increasingly apparent.

Shah et al. outlined four criteria for identifying the functionality of XR simulators as omni-learning tools for urology [19]. The first criterion is the degree of visual reality. This appraises the visual fidelity of the immersive experience and how realistically the procedure is represented on the simulator. Although this facet is beneficial and improves the learning experience, there is conflicting evidence on the objective benefits of high-fidelity vs low-fidelity simulators. The second criterion is the physical reality, or the degree to which the virtual tissue behavior parallels real-life tissue dynamics. Thirdly, XR must display physiological reality, such as muscular contractility, pulsatile vasculature, etc. The fourth criterion is the tactile fidelity of the tissue. For instance, virtual reality simulators, such as the Simbionix URO Mentor™ permit learners to handle tissue in a dynamic manner, using the appropriate degree of pressure for different tissue types.

25.4 Evidence-Based Simulation

Due to the diverse range of immersive XR-technology modalities available, a focused, targeted, and purpose-built approach can be used with respect to surgical training. Broadly, this can be divided into theoretical, practical, and communication-based categories (Fig. 25.2). The evidence base for theory-based teaching primarily centers on anatomy and enhancing textbook learning. The majority of XR-systems are validated for use as task and procedure-based trainers and are classified according to the type of surgical technique and the equipment involved, e.g. endoscopic, laparoscopic, robotic. Finally, the communication-based applications of XR-systems consider their use in enhancing real-life operating theater team dynamics, communication, and proctorship.

25.4.1 Immersive Technologies for Knowledge and Theory-Based Teaching

Insufficient knowledge of anatomy is reported as a major cause of decreasing operative competence among surgical trainees [20]. This is precipitated by the advent of minimally invasive surgery and the minimized field of view, which further distorts the complex anatomy and requires advanced orientation and spatio-temporal reasoning. In Urology, common intraoperative errors made by both novices and experienced surgeons include perforation or injury to the urinary tract, autonomic

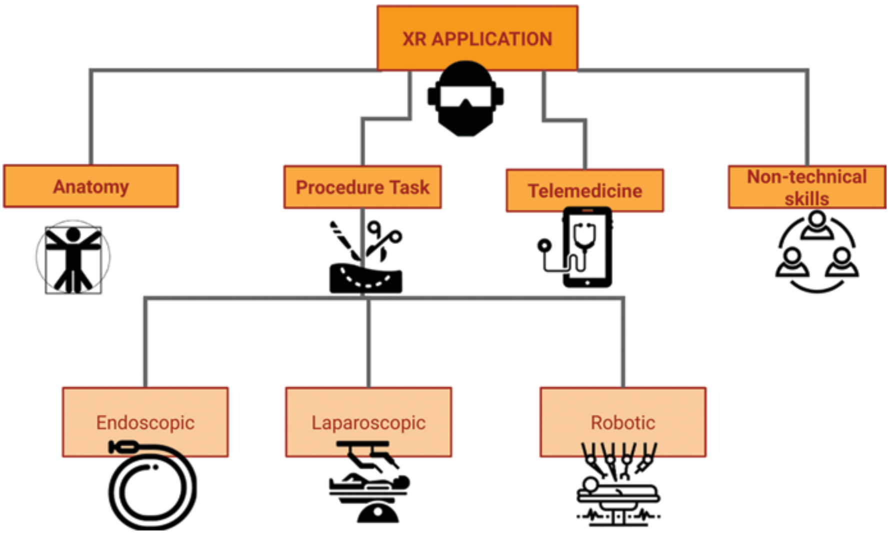

Fig. 25.2 Immersive technology simulation in surgical training

dysfunction following nerve damage and improper positioning of stents, resulting in sepsis [21]. Across medical and surgical specialties, one of the most prominent applications of immersive technologies is in the teaching of anatomy. For a long time, simulation utilizing biological tissue derived from either animals or cadavers was considered the gold standard approach [22]. Cadavers are one of the oldest simulation modalities and are used by surgeons throughout their career and professional development, from an introduction to anatomy in medical school to practicing procedures outside of the operating theater. The anatomical realism, tissue behavior and properties conferred by cadavers become distorted by the preservation process [23]. Traditional phenol or formaldehyde-based embalming techniques also made it difficult to establish pneumoperitoneum for rehearsing laparoscopic procedures. The Department of Anatomy of the University Medical Centre of the Erasmus University in Rotterdam pioneered the AnubiFix® embalming technique specifically to address this issue, maintaining tissue elasticity for laparoscopic training as well as trauma. Nevertheless, due to the limited availability, ethical implications, and high procurement costs, each cadaver has a high trainee to trainer ratio, with as many as seven students around a single cadaver. This renders them costly, with a low re-usability factor, and impractical for personalized learning [24].

XR technologies are typically used in the teaching of gross anatomy through exploratory learning, allowing learners to navigate and virtually dissect body systems [25]. In contrast, surgical anatomy is often taught as a sub-module on procedure-specific trainers. Anatomically accurate computer-generated imagery is achieved through datasets obtained from imaging studies, including computer tomography scans and magnetic resonance imaging. This approach is seen in the "Male Visible Human Project" (National Library of Medicine, USA). Pre-segmented medical imaging datasets of the male pelvic organs, including the urinary tract and reproductive system and the relevant major vessels [26]. Using AR, this database of 3D images may be projected onto a physical 3D pelvic model to facilitate depth perception and spatial reasoning [27]. A similar AR approach is used to enhance learning from anatomy textbooks, using "Gunner Goggles," which project additional information and quizzes onto the original content, using a QR code or scanned image icon [28]. Most immersive technologies feature simplified artwork illustrations to aid understanding and increase the degree of interactivity. This can be seen in the Oculus Rift fully immersive VR headset and the AR HoloHuman application for the Microsoft HoloLens [29]. Several studies have demonstrated that one of the main advantages of this approach is increased learner motivation [30, 31].

25.4.2 Immersive Technologies, Task-Training, and Procedure-Based Training

Physical simulators such as classical bench models or modern 3D printed training models are typically used for training novices in specific tasks or basic skills (Table 25.1). The lack of complexity renders them less useful in the latter stages of

Table 25.1 A list of the commonly used simulators in urology, their validity status, and evidence-base

Category	Simulation Model	Validity and study reference	Kirkpatrick level	Level of evidence	Level of recommendation
Endourology	URO Mentor™	Face, content, construct, predictive [32–34]	4	I	A
	PERC Mentor™	Face, content, construct, predictive [35–37]	4	I	A
	Pelvic Vision	Face, content, construct [38]	3	II	B
	UroSim/TURP Sim	Face, content, construct [3, 39, 40]	3	II	B
	MyoSim	Construct [41]	2	III	C
	CyberSim	None [42]	2	III	C
	GreenLight simulator	Face, content, construct [43, 44]	4	II	B
	Perk Tutor (AR)	None [45]	2	III	C
	HoloLens	Face, content, construct [29, 30, 32, 46]	3	II	C
Laparoscopic urology	Procedicus MIST	Face, content [47]	2	III	C
	LAP Mentor	Face, content, construct [48–50]	3	III	B
Robotic urology	Mimic dV-trainer (MdVT)	Face, content, construct [51, 52]	4	II	B
	Da Vinci surgical simulator (dvSS)	Face, content, construct [53, 54]	4	II	B
	RoSS	Face, content, construct [55, 56]	2	III	C
	HoST	Face, content, construct [57]	3	II	B

(continued)

Table 25.1 (continued)

Category	Simulation Model	Validity and study reference	Kirkpatrick level	Level of evidence	Level of recommendation
Non-technical skills	Igloo and distributed SImulation	Face, content, construct [58, 59]	1	II	B
	High-fidelity operating theatre	Face, content, construct [60]	2	III	B
	TeamSim	None	1	IV	C
	Xperience team trainer	Face, content, construct, concurrent [61]	2	III	B

training and certification. XR simulators address many of the issues regarding interactivity, reusability, and learner engagement which are limiting factors in traditional simulation methods. Due to the highly specific learning curves and skills associated with different urological procedures, full-fledged procedure-based trainers are subdivided according to the minimally invasive technology for which they are designed.

25.4.2.1 Endourology

Endourology accounts for a large proportion of the specialty day-to-day caseload; however, after robotic surgery, these procedures are associated with longer learning curves [62]. This is because endourological procedures encompass a spectrum that ranges from diagnostic procedures to palliative or curative procedures, such as percutaneous nephrolithotomy, transurethral resection of the prostate (TURP) or transurethral resection of bladder tumors (TURBT) or a combination of both, as seen in cystoscopy and ureteroscopy. As these procedures take place using natural orifices and closed cavities, they are easily replicated in simulation training, and therefore account for a large proportion of the XR simulation modalities available. The vast majority of validated VR simulators in endourology focus on training for prostatic procedures, with fewer platforms dedicated to ureteroscopy and TURP [63].

The VR simulator URO Mentor™ (Simbionix, USA) is one of the most well-established trainers for urolithiasis using semi-rigid and flexible ureteroscopy (URS), demonstrating all levels of validity [32–34]. This incorporates computer-generated patient-specific anatomy with a wide spectrum of clinical scenarios, featuring stones and strictures of different sizes and at different locations within the urinary tract. Learners are able to practice the procedure using real-life instruments, such as the ureteroscope, guidewires, and baskets. URO Mentor™ also facilitates the appraisal of trainee performance through predefined objective performance metrics.

Randomized controlled trial evidence also demonstrated that the use of the simulator not only correlates with marked improvement in learners' technical skills and reduction in task completion time, but that these skills also translate well into the operating theater [64]. This platform has also been validated at all levels for use in combination with the PERC Mentor™ (Simbionix, USA) for PCNL [35–37]. Another example is the GreenLight SIM Virtual Reality System (Boston Scientific, USA). This platform has received extensive validation, with several studies attesting to its face, content, and construct validity [43, 44]. Similar to the URO Mentor™, this platform features a curriculum that includes both task-training and procedure-training, featuring five and six modules, respectively, to facilitate stepwise progression of competency.

UroSim (VirtaMed AG, Switzerland) is a VR trainer adapted for a wide range of endourological procedures, including TURP, transurethral resection of bladder tumors (TURBT), and holmium laser enucleation of the prostate (HoLEP). These are presented as separate modules, each of which has been validated for face, content, and construct validity [39, 40, 65]. This is a perpetually evolving and expanding platform with several commercially available adaptations, including MyoSim and CyberSim. The MyoSim VR platform has been used for procedure-based training in photoselective vaporization of the prostate (PVP), and has received construct validation [41]. CyberSim was developed as a trainer for thulium vaporesection of the prostate (ThuVaRP) and lithium laser enucleation of the prostate (ThuLEP), although this platform has not yet been validated [42]. Many VR simulators for endourology are of limited use due to the fact that they are outdated, not commercially available, or insufficiently validated. One of the first XR simulators to be developed was the VR TURP simulator by University College London. While there have been studies demonstrating the content validity of this simulator, it has fallen out of use due to the relatively outdated interface, which poses limitations in the visual and haptic quality of the simulator [66]. Other VR simulators available for TURP include the PelvicVision (Melerit Medical AB, Sweden) platform [38]. The face, content, and construct validity of this model has been demonstrated, with participants noting the benefits of the high-level anatomical guidance and realistic flushing, draining, coagulation, and resection functions [67, 68]. At present, the most extensively validated VR simulator for TURP is the SurgicalSIM TURP, with numerous studies having demonstrated face, content, and construct validity [69]. The construct validity and ability to distinguish between novice and expert performance can be attributed to the inbuilt evaluation metrics, which can be used to generate a performance report on specific technical skills. Specifically, the construct validity study demonstrated that surgical trainees's performance on the simulator on parameters such as gram-weight measured resection, use of irrigation, and time spent managing bleeding correlated strongly with previous TURP experience [67].

The second most popular XR technology used for training in endourological procedures is augmented reality. Nevertheless, there is a paucity of evidence available due to the relative novelty of this technology. Prominent examples include the Perk Tutor (Queen's University, Canada) and the Microsoft HoloLens. The former has been used for tracked-ultrasonography-snapshot (TUSS) guided percutaneous nephrostomy (PCN); however, this has not yet been validated and is not commercially available [45]. Augmented reality technologies, such as the Microsoft HoloLens, have been validated for use as adjuncts in the operating theater for endourological procedures as an alternative to the traditional fluoroscopy monitor for image guidance. The HoloLens headset can be used to project the imaging data directly into the surgeon's field of view, thereby minimizing the frequency of focus-shifts and promoting ergonomic practice [46].

25.4.2.2 Laparoscopic Procedures

The use of immersive technologies is a relatively recent development in the context of laparoscopic surgery. Simulation training was previously dominated by bench models and box trainers. These fostered a skills-based approach rather than a procedural run-through, with the primary objective of being familiar with the instruments and isolated, basic surgical skills, such as peg transfer, suturing, and knot tying. A study by Steigerwald et al. demonstrated that there was little difference in the technical skills and performance in the operating theater, demonstrated by novices that were trained using box-trainers versus those trained using immersive technologies [70]. The defining feature of laparoscopic XR simulators is the use of haptic or force feedback which is integrated into real-time assessment against pre-defined performance metrics.

The Procedicus MIST (Mentice, Sweden) VR platform was developed as a trainer for laparoscopic nephrectomy. This simulator is no longer commercially available, as one study demonstrated that construct validity could not be established among a larger participant cohort size [47]. Examples of commercially available VR laparoscopy trainers include the LAP Mentor (Simbionix, USA) and LapSim (Surgical Science, Sweden). While these platforms are designed to operate as both task trainers and procedure trainers, only the basic surgical skills task-training modules have been validated [48–50].

25.4.2.3 Robotic Surgery

The introduction of minimally invasive and robotic procedures as alternatives to open surgery has significantly improved primary and secondary surgical outcomes, and the morbidity associated with the procedures for which these techniques are available [71]. Nevertheless, the success of these operations is grossly dependent upon the technical and clinical expertise of the principal surgeon [72]. Acquiring proficiency for such procedures is more arduous due to the often counterintuitive psycho-motor operating axis and limited field of view [73]. For this reason, RARP XR simulators must feature stepwise progression from task training through basic robotics skills to full procedural simulation. The validation of these XR simulators, their inbuilt recording capacity, and the strong evidence base backing their educational value in reducing learning curves makes them suitable for objective assessment of technical skills.

Another issue to consider is whether the XR is a standalone training system, such as the Mimic da Vinci Trainer (MdVT; MIMIC Technologies, Seattle, WA, USA) or if it is to be used as an adjunct to the da Vinci console, such as the da Vinci Skills Simulator (dVSS). The MdVT is the most well-established VR simulator for robotic surgery, demonstrating all levels of validity, and featuring a design which closely resembles the da Vinci robot [51, 52]. The main disparity is that the hand controllers of the simulator are not connected to the robotic arms but to tension cables. Full-length procedures, such as RARP, are broken down into modules delineated by the operative steps. Concurrent and predictive validity were established for this simulator using the urethro-vesical anastomosis module by Kim et al. [53, 54].

The Robotic Surgical Simulator (RoSS; Simulated Systems, Williamsville, NY, USA) trainer is an analogous system to the MdVT, with several studies demonstrating transferability of skills between the two trainers and improvement in task completion time [55, 56]. RoSS is principally used for the development of basic and intermediate surgical skills, with the curriculum focusing on Fundamental Skills of Robotic Surgery (FRSR). Unlike the MdVT, it is of limited use as it is only available in the USA. The dVSS can be attached to the da Vinci robot, thereby converting the real-life console into a VR simulator [52]. However, the codependence of the dVSS on the robot means that its use is limited by the availability of the da Vinci robot, which may make it impractical for training during times of increased operative caseload [63].

In recent years, adjuncts have been developed to supplement MdVT and dVSS trainers with modular curricula and training goals, as well as with additional XR, such as the augmented reality based MaestroAR (Mimic Technologies, USA). This programme comprises computer-generated 3D videos illustrating the relevant surgical anatomy for partial nephrectomy, prostatectomy, and low anterior resection, with the intention to establish awareness of benign and potentially hazardous anatomical variations [74].

The program replicates the traditional mentorship experience by using subject-matter expert (SME) commentary to guide the trainee through each crucial decision-making stage, building upon the cognitive task analysis (CTA) pedagogic approach for instructional design. The partial nephrectomy module is currently validated through face, content, construct, and concurrent validity. The Hands-on Surgical Training (HoST) system is an augmented reality tool used as an adjunct to the RoSS. A wide range of modules have been developed, including prostatectomy, cystectomy, and lymph node dissection. A randomized controlled study comparing the HoST software with the dVSS system as standalone trainers determined that HoST was also valid and feasible as an independent training tool for robotic surgery [57].

25.5 Non-technical Skills and Communication-Based Training

25.5.1 Non-technical Skills

There are a few options dedicated exclusively to appraising non-technical skills. Currently, in urology, the only evidence-based approach for this is as part of a distributed-simulation (DS) approach, where within a simulated operating theater

“Igloo” (Imperial College London, UK) [58, 59]. This is a portable, low-cost modality which simulates the operating theater setting. As a human-performance simulator, it is particularly valuable in establishing team dynamics and familiarity with the operating theater environment. Brewin et al. demonstrated the utility of this modality in non-technical skills training within Endourology [75, 76]. Trainees are given a clinical scenario which they have to lead and an XR simulator on which they complete a procedure. Trainees are asked to lead the actors, posing as theater staff, as if it were a real-life procedure. In contrast to XR immersive technologies, human performance full-scale immersion simulations have been shown to benefit from higher fidelity, with audio-visual factors, such as operating theater sounds and lighting playing a significant role in the value of the experience [77]. This was demonstrated in the context of a high-fidelity simulated operating theater, using a dry-lab model as the procedural simulator and manipulating the scenarios’ level of difficulty with complications [60]. It was concluded that such fully-immersive simulations may be beneficial to both trainees and expert surgeons. In the latter category, this principally supports improvement of non-technical skills and team dynamics. However, a randomized controlled trial by Lendvay et al. also demonstrated that the clinical performance in robotic surgery of expert surgeons was ameliorated following an immersive XR pre-session “warm-up” [78]. Furthermore, Bruckhorst et al. demonstrated that in the absence of specific XR training platforms, DS and full immersion simulation can be used to enhance non-technical skills if they are used in conjunction with a purpose-built, validated, and comprehensive curriculum [76].

One of the main criticisms of DS is that the procedure is not an accurate depiction of clinical practice as it presents scenarios or surgical procedures in isolation and therefore lacks important clinical context. To address this issue, Imperial College London has developed the concept of sequential simulation (SqS) [79]. This advocates immersive clinical simulation as an iterative process, factoring in several stages of a patient’s care pathway, allowing trainees to establish a wider, context-specific arsenal of non-technical skills, alongside a more in-depth understanding of patient journeys. However, although promising, this has not yet been validated and organizing such simulation events is logistically complex. Equipping facilities with the appropriate environmental cues could increase the fidelity of the DS, but requires investments in time, money, and effort [80] with considerable costs for actor and venue hire and hidden costs associated with disposable equipment, such as surgical trays, gauzes, drapes, etc. In addition, recording systems used to obtain session data for review can incur additional costs if they are not already integrated as part of the XR simulator [81].

Beyond human performance simulators such as DS, a number of XR technologies have been designed specifically with modules for team training and non-technical skills. Some are designed to be used in conjunction with VR-procedure trainers, such as the TeamSim (Surgical Science, Sweden), developed for the LapSim VR trainer. The Xperience Team Trainer (XTT; Mimic Technology) is a team trainer for robotic surgery, focusing on improving the synergy between the main surgeon and the assisting surgeon in promoting effective intraoperative collaboration and coordination [61].

25.5.2 Telemedicine

Telemedicine is a variation of the traditional surgical mentorship paradigm, using XR technologies to provide live support and assistance to a surgeon by another surgeon, who is not physically present. Telemedicine encompasses three subdivisions; telecommunication, telementoring, and telesurgery. Telecommunication alludes to virtual conversations and guidance, not necessarily taking place in real-time or in synchrony with the operation. No additional equipment is required. Telementoring is the largest subtype of telemedicine, encompassing teleproctoring, telestration, and teleassistance. Several studies have demonstrated this technique both in the context of early procedural training of novice surgeons and in advanced cases requiring specialist input from an expert that may be in another center [82]. AR head-mounted displays are used to establish a telelink and to transmit and live-streaming images from the "surgeon's eye-view," with the remotely assisting surgeon being able to annotate the surgical field and direct the operating surgeon [83]. In this scenario, teleproctoring refers to the assisting surgeon's verbal input and guidance, while the ability to annotate and draw on remote monitors to illustrate a point constitutes telestration. The first-person perspective of the surgeon's viewpoint has also been shown to be beneficial in remote observership, improving the experience for trainees and other members of the surgical team. Teleassistance refers to the ability to offer assistance by controlling the camera or remotely handling the instruments. In urology, international telementoring has already been successfully established, with evidence showing that it is particularly valuable in laparoscopic procedures and robotic surgery. Telesurgery can take place exclusively on a robot, such as the AESOP (Automated Endoscopic System for Optimal Positioning), PAKY-RCM (Percutaneous Access to the Kidney Remote Center of Motion), and the Da Vinci "master-slave" system. A transatlantic randomized controlled trial between the UK and USA in telerobotic surgery compared manual surgery with robotic surgery and transatlantic telerobotic percutaneous needle access on the PAKY-RCM for a validated kidney model [84]. This demonstrated that while robot-assisted insertions took significantly longer than manual insertions, they achieved greater accuracy levels and required fewer attempts.

Several factors influence the success of this process, namely the need to establish a stable connection, with minimal interruptions, delay, or lag between images and ensuring that the data is transmitted securely and in a way that protects patient confidentiality [85]. Because of these ethical, technical, and financial concerns, telementoring has not gained the momentum that was originally predicted. In many cases, studies have shown that it may be necessary to purchase additional recording equipment, such as high quality cameras, establishing secure WAN (wide area network) or LAN ("local area network") connection with sufficient bandwidth and selecting light-weight head-mounted displays with stereoscopic capacity. Challacombe et al. proposed that one method for overcoming the issues regarding security and confidentiality is to appoint an international committee responsible for overseeing and modulating the implementation of telemedicine [86].

The majority of the current literature that is published on the use of immersive technology in urology discusses how XR can be used to optimize ergonomic efficiency and reduce the number of focus shifts during an operation [87]. The most suitable XR modalities for this purpose are the partially-immersive devices, such as AR and MR. These can provide intraoperative guidance to a surgeon, such as the extent of tumor metastasis, ureteric stone position, vascular integrity, tissue viability, etc. Projecting the radiological data into the surgeon's field of view significantly reduces the number of focus shifts, albeit slightly increases the operative time [88]. Nevertheless, the benefits of continuous intraoperative guidance are superior to static X-ray, CT or MRI scans, which can only provide information about the clinical picture at one point in time and any change in the clinical picture warrants further scans and additional patient exposure to ionizing radiation, which also incurs additional costs.

Another benefit of XR in the clinical setting is seen in improving pre-operative planning practices. Currently, preoperative planning revolves around the generation of a theoretical plan based on imaging studies and team discussions. The main issue with this strategy is that when intraoperative issues arise, they may derail the plan and lead to rash judgments and unacceptable, preventable complications [89]. Some of the more advanced immersive technologies available allow a surgeon to rehearse a procedure from start to finish, factoring in patient-specific conditions or anatomical variations. They may also practice how to manage any potential complications.

25.6 Future Directions and Recommendations

Future directions and applications for immersive technologies in urology can be identified by looking at the applications of XR-technologies in other surgical fields. In general surgery, virtual reality has been used to improve pre-operative planning practices and intraoperative team dynamics by pre-operatively devising a "surgical map," which can be accessed and referenced intraoperatively [90]. Afterward, these maps could be used to improve future performances by gaining insights into the operation and different surgeons' approaches. This contributes to enhanced clinical documentation and ameliorating enhanced auditing practices and compliance with guidelines and improve the efficiency of service delivery [91]. This is crucial across all surgical specialties, as healthcare services around the world struggle with the loss of time and money in surgical delays and cancelations. As one of a hospital's most expensive resources, theater hire can cost up to £ 561 p/h [92]. This figure excludes supernumerary costs procured by wasted or additional resources. It is also well known that surgeries with complications also triple the cost of those without.

Preventable errors and near-misses lead to rising litigation costs. In the UK, the cost of such malpractice procedures is predicted to quadruple by 2023. Aside from their impact on primary surgical outcomes, complications adversely impact secondary surgical outcomes, such as the proportion of 30-day readmissions. These are estimated to cost the NHS £583.7m per annum [93]. Beyond these clinical outcomes, it is most important to diminish the human costs of such adverse events, such as the impact on the quality of life of both patients and their families. XR provides unique prospects for medico-legal inquiries, using simulation technologies for investigating surgical near-misses or never events by reproducing the clinical scenario in question, evaluating how different surgeons would have responded to these scenarios, debriefing the team and contributing toward the development of future preventative practices and policy [94]. Furthermore, the impact of an increasingly aging population with multiple comorbidities has led to the advent of hyper-specialization. In this context, immersive technologies can play a catalytic role in supporting standardization initiatives. XR can be used to "democratise"; access to procedures and surgical innovations. NICE reports on the postcode lottery and preventable inequalities in healthcare highlight the importance of creating better service opportunities in underserved populations [95]. Often, there is variability in the quality of teaching received by trainees based on the Trust they are allocated. This is a complex and multifactorial issue; however, the causative mechanism at the heart of the matter is disparity in case exposure and distribution and limitations in funding for facilities and training programs. Both trainees and experienced surgeons working in remote areas, without much exposure to rare cases, have limited experience with certain procedures and could use immersive technologies such as telementoring to learn and rehearse such procedures. This could reduce the need for patients to travel to distant hospitals in order to access services, or to receive a higher standard of care [96]. Immersive technologies can also be used to enhance clinician communication skills and to promote patient health literacy. XR can be used as a consultation aid, facilitating patient understanding of the procedures and endorsing a patient-centric model of care that promotes more effective collaboration [97].

In response to the COVID-19 pandemic, nearly a decade after they were drawn, the 2009 Crisis Standard of Care guidelines of the Institute of Medicine were implemented. These emphasized the importance of multidisciplinary collaboration in navigating issues such as altered service delivery and shortages of personnel [98]. One way in which this was addressed, was by re-certifying retired professionals and trainees who were subsequently fast-tracked into clinical practice. Research into methods for accelerating training and certification using virtual technologies was still in its infancy. In 2012, following the enquiry on the impact of the EWTD on specialist surgery, the RCS recommended that a way to simultaneously improve surgical outcomes and address the NHS staffing shortage is to maximize the skillset of the core and extended surgical team. This proposal was based on a pilot study conducted in one of the busiest emergency surgery departments in the UK, at the University Hospital of Leicester NHS Trust. Here, XR was utilized to pilot an Advanced Nursing Practitioner (ANP) scheme, training selected nursing staff to perform tasks at the same level as junior doctors. The program was successful, with the principal advantages being delegation and alleviation of clinical commitments for trainees, allowing them to focus on surgery [99]. Although there is an inherent need for appropriate supervision, the RCS considers this "a logical extension of the use of such practitioners in the elective care setting" [100].

25.6.1 Recommendations for Improving Cost-Effectiveness

As the demand for XR increases, so do the options available. It is a misconception that XR must be expensive in order to be effective. Equipment can range in price from £10 smartphone or tablet-based devices, as with Google Cardboard, to the £ 3000 Microsoft HoloLens. Therefore, it is evident that affordability is high, especially when considering the high reusability factor of such technologies, which implies purchase of relatively few individual units per institution. The certification of XR skills can prevent duplication of efforts and retraining of staff in accordance with local Trust guidelines. This can also help to ensure standardization and quality assurance. Using the XR to retrain existing staff can mitigate the cost of hiring new staff to operate the XR labs or new technicians to handle repairs, it is preferable to reduce transition costs through block retraining of the existing technical support workforce. In the context of teaching, immersive technologies can be used to champion automation of the learning process. The high trainer: learner ratio in XR can be addressed by generating an entirely self-run process, through modalities such as telementoring and video-briefing. Learners can then review their performance with their educational supervisors, thereby eliminating their physical presence in simulations. There is growing interest in the use of immersive technologies as platforms for trialing novel surgical techniques, tools, and pharmaceutical candidates without the initial concerns for ethical recruitment and patient safety which exist in current research on surgical innovation. Additionally, simulators can be used to pilot research into which factors affect surgical performance, such as sleep-deprivation, the acceptable thresholds of theater noise, and distraction without hindering surgical performance, etc. [101]. Immersive technology-based research can be used to generate significant extramural funding for institutions while simultaneously generating multi-institutional research collaborations both nationally and internationally. This can generate income for the Trust and contribute toward the running and maintenance costs [102].

25.7 Summary

Proposals on refining the process and product of surgical training must consider both the curriculum content and the interface of delivery. This requires high-fidelity curricula with evidence-based educational impact. The paradigm shift in surgical training from “modern apprenticeship” to “point of need learning” reflects a necessity to fulfill novel educational needs, while retaining time-honored principles in surgical education, such as mentorship.

The initial procurement costs for immersive technologies are far outweighed by the low maintenance and operational costs and the comparatively greater costs of inadequate or insufficient training. This is true in terms of both monetary and non-monetary factors and for surgeons, patients, and healthcare institutions alike.

Immersive technologies can help clinicians navigate care during a time where patients expect that staff will be sufficiently, if not proficiently, trained before they undertake procedures on them. In the operating theater, XR offers the ability to optimize safety levels by diagnosing flaws in plans or deficiencies in skills before they have a chance to manifest in practice. In the education of trainees, immersive technologies can provide the right level of education, at the right time, as well as the efficiency required to address the primary concerns of modern surgical trainees. For senior clinicians, it significantly contributes to the process of improving outcomes for morbidity, mortality as well as improving and personalizing outcomes in elective procedures.

Evidence-based simulation in urology has evolved symbiotically with advancements in technology and pedagogy. However, from the evidence available, it becomes clear that the most lucrative educational approach entails a structured and purpose-built curriculum. This selects the most appropriate simulation modality for the task and the trainee's educational stage. In the interest of stepwise progression from familiarity, to competence, to proficiency, the best results can be achieved through a strategic combination of multiple simulation modalities. This would optimize the curriculum's validity, pedagogic value, and cost-effectiveness.

Key Points

- Immersive technologies either simulate or enrich the user's physical environment using virtual components. This is labeled as "XR" where "R" stands for "reality" and "X" represents the degree of immersion "Virtual/Augmented/Mixed" Reality.
- These technologies have a deeply rooted provenance in aviation industry training, where pilots, like surgeons are placed in a safe environment to rehearse technical and non-technical competencies.
- As a specialty, urology is at the forefront of pioneering work in simulation, as the surgical techniques used are well-replicated in both low- and high-fidelity simulation contexts.
- The value and need of high-fidelity simulation beyond the operating theater was widely recognized following the European Working Time Directive and most recently, by the disruption to elective services caused by the COVID-19 pandemic.
- Immersive technologies are beneficial both in formative surgical training, aiding the development of technical and non-technical skills, as well as in continuous professional development and real-life operative setting. This facilitates an "omni-learning" approach.
- XR technologies can be used for formal assessment. Certification and performance appraisal must be subjected to a rigorous review and validation process, using a standardized evaluation method, e.g. face, content, construct, and predictive validity assessment metrics.

- Evidence-based XR simulators in urology exist for a variety of applications, including surgical anatomy navigators, task-trainers, procedure-trainers for endourology, laparoscopic and robot-assisted procedures. At present, there are only a few XR options dedicated exclusively to appraising non-technical skills.
- Beyond training, XR applications such as telemedicine (telecommunication, telementoring, and telesurgery) enable real-time intraoperative communication and collaboration.
- XR technologies are reliable and cost-effective tools, with initial procurement costs offset by low maintenance and operational costs and the comparatively greater costs of inadequate or insufficient training.

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Chapter 26
Role of 3D Technology in Simulation

Francesco Porpiglia, Paolo Verri, Enrico Checcucci, Daniele Amparore, and Cristian Fiori

26.1 Introduction: What Is a 3D Model?

Currently, we are entering the era of industry 4.0, based on the computerization of the productive chain. A transformation toward new work models, based on the latest technologies, is taking place every day [1]. Among the new incoming technologies, three-dimensional (3D) technology exemplifies a particularly interesting field, which has been the object of constant development and research in several industries. Before exploring the application of this innovative technology, we have to ask ourselves: what is a 3D-model?

A three-dimensional model (3D-model) is a virtual or physical representation of the surface of an object. Depending on the technology involved, it can be obtained by using dedicated software program (virtual model) or physically manufactured. The operator (i.e., modeler) translates and reproduces an object's characteristics into a final product, using various technologies. Looking back in time, we could say that a great artist such as Michelangelo Buonarroti was actually an ancient 3D-modeler: while creating one of his masterpieces (e.g., "La Pietà") the artist shaped a mental (i.e., virtual) image into his final creation (i.e., a physical model). Technological evolution and the computer's creation led to great innovations, which allowed artists and scientists to create and benefit from new techniques, changing the status quo of their respective fields. The movie industry, for example, was transformed by the creation of movies such as "Avatar" (directed by James Cameron, distributed by twentieth Century Fox, 2009). The art industry was turned upside

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down by artists such as Ebon Fisher and Joseph Nechvatal, who were later referred to as "virtual artists" by art historians such as Frank Popper.

Focusing on medicine, the application of 3D technology was revealed to be particularly interesting in the surgical disciplines. In the last decades, operators have been increasingly interacting with machines, leading some authors to theorize the advent of the aforementioned "surgery 4.0" era, in which machines controlled by humans can overcome limits once thought to be unimaginable.

Surgery, despite technological advances, still builds its solid foundations on anatomy. In each individual, the body is at the same time identical and different, so every patient must be thoroughly studied. Following this principle, several authors have analyzed the usefulness of 3D technology in their clinical practice, to create patients' specific models in order to perform tailored surgery. Therefore, 3D technology has been applied to different fields, starting from surgical planning to surgical navigation.

Surgical simulation perfectly fits into this scenario: prior to the actual surgical act, novice and expert surgeons can practice, discuss, and study the case with colleagues (i.e., surgical planning) using 3D models.

In this chapter, we will try to guide the reader through the world of 3D modeling, providing information on the building process and the clinical applications in surgical simulation.

26.2 How to Create a 3D Model?

Radiological imaging, such as CT or MRI, represents a fundamental step in the diagnosis and treatment planning of most urological diseases since it offers a complete overview of a patient's anatomy. However, the precise understanding of anatomical structures can be tricky, in particular for inexperienced urologists [2]. In fact, in order to perform an effective "building in mind" process, every surgeon has a learning curve, which takes time to get better of. As intuitive as it can be, 3D reconstructions provide information, which is more easily accessible when compared to 2D CT/MRI images: proportions and relationships between nearby organs are more understandable and the pathology itself (whether malignant or benign) can be displayed and visualized in different viewing modalities.

3D models are made by starting from bi-dimensional images: all the popular DICOM viewers software offer, by default, the opportunity to create three-dimensional reconstructions thanks to an automatic rendering process, but the quality is often unsatisfying.

Notwithstanding the poor quality of these models, they can be useful to overcome the limits of the 2D images, adding some information and details thanks to a spatial visualization of the organs and of the disease's features.

However, surgeons usually need to have more accurate models and, in order to realize them, the introduction of the specialized bioengineer into the teamwork was needed. This new team member provides a service aimed at creating better models in terms of details and anatomical accuracy.

The success of this process is strictly connected to the ability of doctors and engineers to interact with one another. The engineers need to understand the surgeon's requirements and vice versa, in order to create an accurate computer project.

The realization of the models starts with the acquisition of 2D images of the patient. The most useful material is obtained by CT scan (multi-slice is preferred), which can be easily exported in DICOM format; MRI images can also be used.

A high-quality imaging is fundamental since it increases the precision of the 3D reconstruction. In particular, the thickness of the single slice should not exceed 5 mm.

First of all, using DICOM images displaying software, the object must be analyzed and studied in 2D, selecting the most useful images (e.g., arterial or late phase of a CT-scan) and modifying specific parameters (e.g., image contrast and luminosity) according to the project's needs. This phase is named the "preprocessing phase."

Next is a volume rendering. In this phase, an initial version of the 3D model is generated automatically by the software, using information included in the image voxels. A voxel is the basic volume unit, the equivalent of a pixel in a 2D system. This initial rendering gives an overall idea of the project, allowing the engineer to identify critical issues.

Afterwards, using dedicated software, a process called "segmentation" is performed. Segmentation is defined as the isolation of pixels included in regions or objects of interest (ROIs/OOIs), selected on the basis of a subjective similarity criterion (e.g., color). The easiest process to identify different ROIs/OOIs is called "thresholding." The engineer can select a specific range of a defined parameter (e.g., gray scale) in order to allow the software to identify all the regions with the chosen characteristics. Specific algorithms are generated, and other regions/objects are automatically discarded. This is a fundamental step in the realization of the 3D models: in some cases, the software is not able to correctly identify and depict the different features and this process needs to be done manually. At this stage, the role of the engineer is fundamental, and the acquired experience allows us to tailor the patient's specific 3D model, almost as a craftsman with his artifact would do.

Once this process is completed, the project can be exported and saved in .stl (Standard Triangulation Language) format, which allows the operator to perform further modifications to the rendering, using dedicated software. At this point, the virtual 3D model is completed (Fig. 26.1).

Once the 3D model is obtained, it can be uploaded on different electronic devices (*see subchapter below*) for its virtual three-dimensional visualization or, it can be printed using dedicated hardware (Fig. 26.1).

Nowadays, different 3D printing technologies are available, each of which has different characteristics and potential applications [3].

Below we report a brief description of the most popular 3D printing technologies (Table 26.1 and Fig. 26.2):

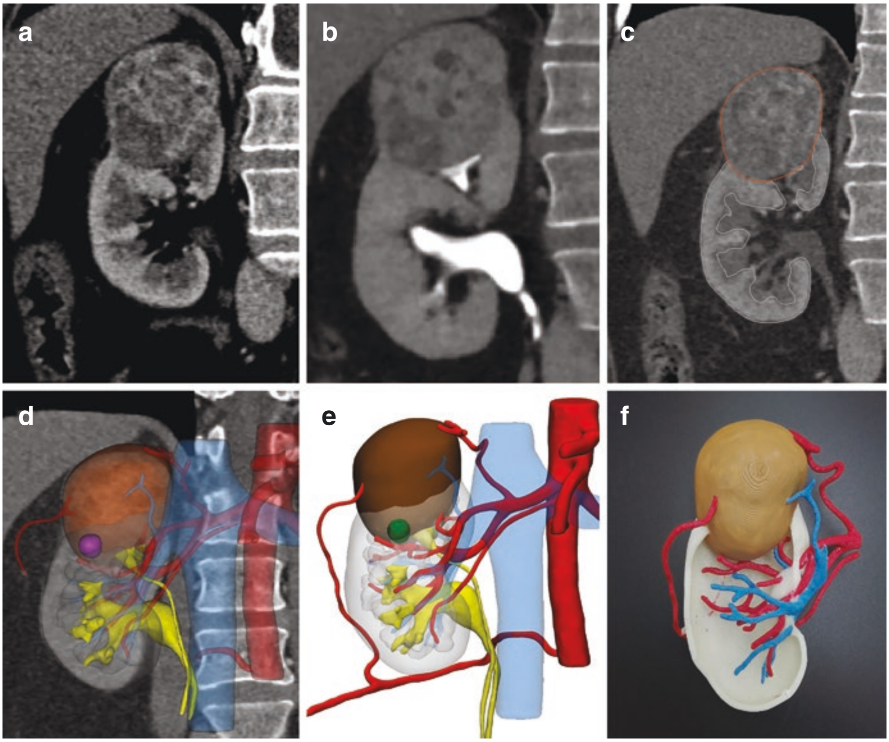

Fig. 26.1 3D model processing: (**a**) CT scan; (**b**) c.e. CT scan; (**c**) segmentation phase aimed to identify the different anatomical structures; (**d**) 3D model obtained can be overlapped to the CT images; (**e**) hyper-accurated 3D virtual model; (**f**) 3D printed model with FDM technology

Table 26.1 Summary of the different features of the 3D printing technologies (SLA: StereoLithographic Apparatus; SLS: Selective Laser Sintering; FDM: Fused Deposition Modeling)

	SLA	SLS	FDM	Polyjet
Transparency	✓	**X**	**X**	✓
Sterilizable	✓	✓	✓	✓
Soft	**X**	**X**	✓	✓
Multicolor	**X**	**X**	✓	✓
Resolution	0.07–0.2 mm (XY) 0.1 mm (Z)	0.05 mm (XY) 0.06–0.15 mm (Z)	0.25 mm (XY) 0.05 mm (Z)	0.02–0.05 mm (XY) 0.05 mm (Z)
Accuracy	••••	•••	••	••••
Support	✓	**X**	✓	✓
Post production	✓	✓	✓	✓
Cost	**€€**	**€€**	**€**	**€€€**

Fig. 26.2 Different 3D printing technologies: (**a**) Fused Deposition Modeling (FDM); (**b**) Stereolitography (SLA); (**c**) Multi-material Plastic Jetting (Polyjet); (**d**) Silicone mold pouring combined with FDM printing

- Stereolithographic Apparatus (SLA): a liquid polymer is hit by a UV laser, priming a polymerization of the synthetic medium, causing its solidification.
- Selective Laser Sintering (SLS): a thin dusty layer of a chosen polymer (e.g., ceramic, metal, plastic…) is spread and consequently hit by a laser, sintering it.
- FDM (Fused Deposition Modeling): a polymer filament is extruded through a hot nozzle, deposing a thin layer of fused material on an XY plane. Subsequently, the nozzle moves up or down the Z-axis, creating the next layer. Multiple nozzles can extrude different materials, allowing the creation of multi-colored models. When creating particular shapes with protruding edges, the machinery must create a support, in order to avoid the accidental breaking of the model, which will need postproduction processing.
- Polyjet: this machinery is similar to an ink-jet printer. A photo-curing polymer is laid on the XY plane and immediately hardened thanks to a UV lamp, attached to the nozzle. This model is surrounded by a viscous material, providing support in the case of irregular shapes. This feature also requires a postproduction processing.

26.3 How to View the 3D Models?

Surgeons have essentially two different ways of using 3D reconstructions: they can either display them on an electronic device (virtual models) or create a physical object (printed models).

Virtual models are accessible from practically any electronic device (e.g., smartphones, tablets, laptops) and provide an intuitive experience. Since all .stl files can be exported as .pdf files, they can be easily sent via email or dedicated platforms (e.g., MyMedics – Medics Srl©), allowing different hospitals to work together with a team of specialized engineers located elsewhere.

The 3D model can be displayed differently, according to the surgeons' needs and to the hardware's availability (Table 26.2):

- 2D screen (e.g., tablet): the virtual model is displayed on a 2D screen and can be zoomed, tilted, rotated, and translated according to the operator's needs. Depending on the software used, the model can be modified (e.g., transparency, colors). The main limitation of this display method is the absence of 3D vision.
- Mixed Reality (MR—i.e., the superimposition of virtual elements to live images): this setting involves the use of specific instruments, named head-mounted displays, such as the HoloLens® device, which allows displaying of three-dimensional virtual images merged with real environment. This technique, mainly used in preoperative planning, allows you to physically walk around the model and interact with it using gestures. These devices also allow the broadcasting of images, so that an audience can experience what the operator sees through the lenses, live (Fig. 26.3).
- Virtual reality (VR—i.e., a setting in which the operator interacts with a fully virtual environment): thanks to dedicated visors, surgeons are immersed in a totally virtual setting where they have the possibility to interact with the 3D model with specific gestures; it is important to note that in this setting, the real environment is excluded from the operator's vision. Alternatively, VR can be used and thanks to virtual simulators [e.g., for robotic surgery: dV-Trainer (Mimic, Seattle, WA, USA), da Vinci Skills Simulator (Intuitive Surgical, Sunnyvale, CA, USA)] through which surgeons with different levels of experience can practice specific tasks (e.g., suturing, moving objects) or full procedures (e.g., partial nephrectomy, radical prostatectomy) while immersed in a fully digital environment. The most advanced devices also offer haptic feedback, giving an experience which resembles the actual operative scenario.

Table 26.2 Summary of the different display systems for 3D virtual models

	Vision	Environment	Consultation	Clinical application
2D flat screen	2D	Real + Virtual monitor	2D monitor (tablet, smartphone)	Surgical planning
Mixed reality	3D	Virtual + Real	Head-mounted display (i.e., HoloLens)	Surgical planning and surgical navigation
Virtual reality	3D	Virtual	Immersive head-mounted display (i.e., Oculus Rift)	Surgical planning and training
Augmented reality	2D/3D	Virtual + Real	Robotic console	Surgical navigation and training

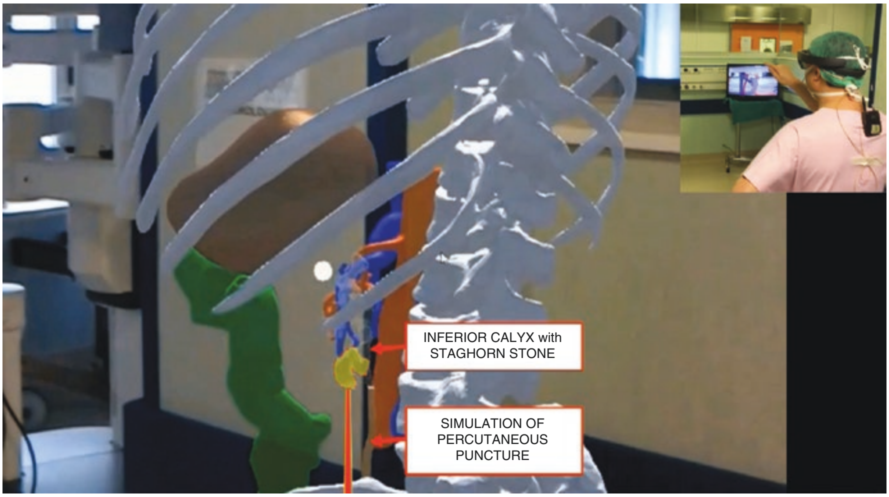

Fig. 26.3 3D Mixed Reality needle route simulation during percutaneous kidney puncture surgical planning for lower pole kidney stone (San Luigi Gonzaga – Orbassano)

- Augmented Reality (AR.—i.e., overlay of digitally created content into the user's real-world environment with the aim of enhancing real-world features). This technique, used mainly intraoperatively, allows the addition of important information during the surgical procedure (e.g., tumor margins, vascular anatomy).

26.4 Application of 3D Models in Urological Simulation

26.4.1 Surgical Training

Simulation applied to surgical training is the main reason why this technology has raised interest in the scientific and surgical world.

In the USA, more than 400,000 deaths per year are due to medical errors [4]. Some of these unfortunate cases are determined by surgical errors, which represent an issue every surgeon will, sooner or later, have to face during his/her career. The Halstedian model, based on the "see one, do one, teach one" paradigm, must be overcome in favor of safe and reproducible teaching methods, which minimize the risk to harm the patient. Following this philosophy, surgical simulation has expanded hugely in recent years.

From virtual simulators to AR and printed models, the latest technologies allow expert and novice surgeons to have a new approach to teaching and learning. In this scenario, it is also important to create instruments which can give teachers the chance to objectively evaluate the trainees' abilities. One of the most used models is called

"Structured Assessment of Technical Skills (OSATS)," which is based on direct observation of specific surgical abilities (e.g., instrument knowledge, tissue handling) that the attendee must show to a team of expert surgeons during a live surgical act [5].

Starting from this solid base but, as previously said, trying to overcome the Halstedian model, evaluation instruments based on virtual exercises were created. The "Fundamentals of Laparoscopic Surgery (FLS)" exam is an adaptation of OSATS for evaluating laparoscopic manual and cognitive skills and involves the use of a bench simulator [6]. Candidates must perform exercises (e.g., stitching, cutting a round shape from a gauze, moving objects in the operatory field) following a determined sequence without exceeding the maximum time allowed. A similar tool has been developed for the evaluation of robot-assisted surgery skills. This is called "Global Evaluative Assessment of Robotic Skills (GEARS)" [7]. By assessing six different domains (depth perception, bimanual dexterity, efficiency, autonomy, force sensitivity, and robotic control), the experimenters were able to validate this tool, which has also been integrated by several institutions as a part of the curriculum.

Notwithstanding the increasing interest that this kind of technology has sparked, there is no gold standard yet.

Simulation platforms can be virtual or physical: both modalities offer a chance to practice specific maneuvers or entire procedures in a safe and controlled environment.

There are several types of simulators, based on different technologies, which are briefly described in the following paragraph:

- OPEN SIMULATORS: these models can either be artificial (e.g., Clinical Male Pelvic Trainer Mk.2 Advanced, Limbs & Things Ltd., Bristol, UK) or obtained from an actual human specimen (e.g., cadaver labs).
- ENDOUROLOGICAL SIMULATORS: whether bench or virtual simulators, allow to simulate almost every endoscopic urological procedure (e.g., UroTrainer, Karl Storz, GmbH, Germany).
- LAPAROSCOPY SIMULATORS: they can be "box trainers" (e.g., eoSIM, eoSurgical™, Edinburgh, Scotland, United Kingdom) or virtual trainers (e.g., Minimally Invasive Surgical Trainer Virtual Reality—MIST-VR, Mentice Medical Simulation, Gothenburg, Sweden).
- ROBOTIC SURGERY SIMULATORS: given the high costs and technical challenges which characterize this surgical technique, VR simulators are the most popular (e.g., dVSS; Intuitive Surgical, Sunnyvale, CA, USA). Nonetheless, when needed, box trainers used for laparoscopy can be used as bench simulators for robotic surgery, using printed or biologic physical models.

Simulators differ from one another, without considering their construction characteristics, by five main features, which are called "validities" and represent the evaluation parameters used for their classification. These parameters are the following:

- FACE VALIDITY: realism of the device, assessed by questionnaires (subjective).
- CONTENT VALIDITY: the ability of the simulator to offer contents and information required in real life; assessed by expert surgeons (subjective).

- CONSTRUCT VALIDITY: the ability of the simulator to distinguish experts from novices (objective parameters).
- CONCURRENT VALIDITY: the comparison between a new simulator and a gold standard.
- PREDICTIVE VALIDITY: the ability of the simulator to correlate the performance on a simulator with an actual real-life procedure.

When evaluating a simulator and its utility, one should consider the aforementioned parameters, in order to match his/her needs with the limits of the machine.

26.4.1.1 3D Virtual Models & Training

Endoscopy of the Lower Urinary Tract

Endoscopy necessarily involves the use of physical instruments (e.g., resectoscope and optical equipment), which must be used together with dedicated software. So, every available simulator, either physical or virtual, must include parts of (e.g., handgrips) or whole surgical instruments. There are several validated simulators, which have been studied and tested. Schulz et al. evaluated the pros and cons of UroTrainer (UT) (Karl Storz, GmbH, Germany), available also in a portable and simpler fashion (Portable UroTrainer - Karl Storz, GmbH, Germany). This simulator includes a resectoscope (with irrigation and drainage function) and a screen which displays the software's content [8]. Their results highlighted good face, content, and construct validity, labeling this simulator as an excellent tool for surgical training, in particular for residents. H. de Vries et al. developed and validated the "Test Objective Competency (TOCO)-TURB" as an assessment tool for evaluating the technical and non-technical competencies of resident urologists. This tool includes the use of the Simbla TURBT simulator (SAMED, GmbH), similar to the UT simulator. Although it needs further improvement, the authors stated its efficacy in evaluating and improving residents' skills [9].

Stones and Ureteroscopy

One of the most well-known simulators is called URO Mentor™ (3D Systems, formerly Simbionix, Beit Golan, Israel) and includes a mannequin connected to a dedicated computer interface, a cystoscope, a semirigid and flexible ureteroscope, plus all the related surgical armamentarium (e.g., guidewires, basket…). The installed software allows the trainee to display the simulated vision of the lower and upper urinary tract, plus to record procedural data, such as the overall simulation time. The included software offers the trainees the chance to practice on different tasks, giving excellent results in terms of improvement of surgical skills. This simulator has been extensively validated, meeting all the aforementioned criteria.

Another platform from a well-known producer is the LYRA URS Trainer "ADAM" (Karl Storz, GmbH, Germany). This platform virtually simulates rigid and flexible ureteroscopy and provides trainees with several exercises and clinical scenarios to practice with, including kidney and ureteral stone extraction, pneumatic and LASER lithotripsy [10].

The treatment of large renal stones frequently requires percutaneous access, which allows the surgeon to treat more effectively this kind of disease. The renal puncture is indeed the most delicate and difficult step of the percutaneous nephrolithotomy (PCNL), the kidney being a highly vascularized organ which anatomical position is influenced by the anesthesiologist's ventilation. For these reasons, simulation plays an important role. 3D virtual simulation platforms necessarily need a physical counterpart, since the simulator itself must give haptic feedback during the puncture. URO Mentor™ (3D Systems, formerly Simbionix, Beit Golan, Israel) has the possibility to also become a percutaneous renal puncture simulator (PERC Mentor™) by adding separately supplied accessories. This, represents one of the most well-known platforms. Thanks to dedicated cartridges fitted with life-like synthetic tissues (i.e., epidermis, connective tissue, costal bones), real needles, and the chance to change the mannequin position (prone-oblique 30 degrees) the trainee can experience a true to life simulation [11].

Laparoscopy and Robotics

Robotic surgery is becoming increasingly available in surgical departments worldwide, which is increasing the need for trained operators. Virtual training is of the utmost importance here, since the surgeon must learn to control over this complex machinery. Among the robotic-surgery simulators, the mostly known commercially available are represented by the da Vinci Skills simulator (dVSS; Intuitive Surgical, Sunnyvale, CA, USA), the Mimic dV-Trainer (Mimic Technologies, Inc., Seattle, WA, USA), the Robotic Surgical Simulator (RoSS; Simulated Surgical Systems, Buffalo, NY, USA), SimSurgery Educational Platform (SEP, SimSurgery, Norway), and RobotiX Mentor (Simbionix USA Inc., Cleveland, OH). The da Vinci Skills simulator is the only platform which is based on the actual Da Vinci surgical console, allowing the trainee to experience the use of the actual machinery. All these platforms allow you to perform basic surgical skills exercises (e.g., suturing) and entire procedures (e.g., robot-assisted radical prostatectomy, RARP) in a fully virtual environment. Several authors [Julian et al., Bric et al., Martin et al.] analyzed the technical differences between the different platforms and their effectiveness during training. All the platforms are validated and demonstrated to offer an optimal experience for trainees and to improve their surgical skills [12].

In a recently published meta-analysis, Portelli et al. analyzed 24 RCTs concerning the impact of virtual training on laparoscopic and robotic surgery. The authors analyzed different parameters, such as time, path length, instrument, and tissue handling and technical skills scoring, including different simulators, demonstrating that the use of virtual training not only improves efficiency in terms of surgical practice but also increases the quality of the surgical act itself, reducing error rates and improving tissue handling [13].

26.4.1.2 3D Printed Model & Training

3D printed models can be custom-made products, which allow high-fidelity anatomical reproductions. This kind of simulation appears to be useful for training young surgeons for all urological procedures. We will briefly describe the application in different procedures.

Endoscopy of the Lower Urinary Tract

The characteristics of benign and malignant pathologies of the lower urinary tract created little interest in developing patient-specific or printed models. The aforementioned physical models and virtual models are the only ones used for simulating these procedures (e.g., cystoscopy, TUR-P, TUR-B). Physical models do not usually involve the use of printed supports, since the costs do not meet the actual benefits.

Stones and Ureteroscopy

Ureteroscopy simulation is currently performed using mainly virtual simulators. The aforementioned technical difficulties for other complex procedures (i.e., PCNL) paves the way for tailored approaches, which can be transformed into training. Several authors have described the creation of 3D printed models for practicing the renal puncture during PCNL. Starting from CT images some authors have created a mold of the excretory system, which was inserted into another mold representing the kidney's surface, as a matryoshka. The gaps were subsequently filled with a liquid polymer, which (after solidification) was meant to replace the renal parenchyma. These patient-tailored models were validated by performing CT scans, ultrasound, and also endoscopy, confronting the obtained data with the patient's characteristics [14]. Other authors, in a pilot study, printed a pelvicalyceal system model using FDM technology and embedded it in silicone. Second year residents, which were divided into two groups (3D printed versus virtual), used this model and a virtual simulator (URO Mentor™) during percutaneous puncture's training sessions. Results highlighted that residents practicing with 3D printed models had better results [15].

In a recently published paper, Farcas et al. compared several simulation platforms: a virtual reality (VR) simulator (PercMentor, 3D Systems™), a porcine tissue simulator (Cook™ Medical), and a new 3D immersive VR simulator-Marion K181 (Marion Surgical™). The authors pointed out how the 3D immersive VR technology represents the optimal tool for training since it offers high fidelity simulation without requiring real radiation exposure [16].

Laparoscopy and Robotics

There are several works exploring the usefulness of 3D printing in surgical training for both expert and young surgeons. Rundstedt et al., generated a pre-surgical model of 10 renal masses with a R.E.N.A.L. score of between 7 and 11. A single expert surgeon performed robot-assisted partial nephrectomy (RAPN) on the patient-specific model and subsequently on the patient. Despite the small number of patients included, the authors showed that the surgeon had an improved perception of the patient's anatomy and felt more self-confident during the most challenging phases of the procedure [17].

Ghazi et al. conducted a multi-institutional validation of a high-fidelity model used for simulating robot-assisted partial nephrectomy, also incorporating the so-called clinically relevant objects of metrics of simulations (CROMS). After creating a three-dimensional model using a 3D printer and polyvinyl alcohol (PVA) hydrogel, a full surgical procedure was simulated using the actual Da Vinci console, with the help of a bedside assistant. During the procedure, the surgeon could practice colon mobilization, renal hilum dissection, tumor exposure, intraoperative ultrasonography, renal artery clamping, tumor dissection, and renorrhaphy [18].

26.4.2 Surgical Planning

The treatment indication maybe the most important crossroad in both the patient's and surgeon's paths. When deciding how to deal with complex pathologies, the surgeon must merge his/her personal experience with international guidelines and recommendations in order to make the best decision for the patient. In this setting, multidisciplinary collaboration is essential. 3D reconstructions can be of help, since surgeons can discuss the clinical scenario, choose the best treatment and the most suitable surgical approach, according to the patient's characteristics. Depending on the lesions and organ's anatomy, the operator can select all the surgical variants. Let us take, as an example, a renal neoplasm: the operator will have to choose the treatment (e.g., radical versus partial nephrectomy), surgical approach (e.g., laparoscopic versus robot-assisted), and the access (e.g., transperitoneal versus retroperitoneal) [19].

26.4.2.1 3D Virtual Model & Planning

Stones and Ureteroscopy

Concerning stone treatment, the major interest is covered by staghorn stones that require treatment with a percutaneous or combined approach, given the complexity of this technique.

Parkhomenko et al. assessed the efficacy of immersive virtual reality (iVR) in the planning of PCNL. Thanks to the use of a head-mounted Oculus Rift display (Facebook Technologies, Menlo Park, CA, US) the authors showed 3D reconstruction of the stones and kidney to both patients and surgeons. Among patients, there was a generally improved understanding of the disease and the planned procedure. Accordingly, surgeons found this instrument very useful, so much so that in 40% of the cases, the surgeon changed the planned approach. Furthermore, the use of this technology determined an improvement in the intraoperative and postoperative variables, such as fluoroscopy time and stone-free rate [20].

Currently, the urology group of San Luigi Gonzaga Hospital (Orbassano – Torino) is experimentally using virtual models to simulate and plan the best way to perform a percutaneous puncture during ECIRS (Endoscopic Combined Intra Renal Surgery), using a mixed reality system. Although no material has been officially published, data seems to be promising (Fig. 26.4).

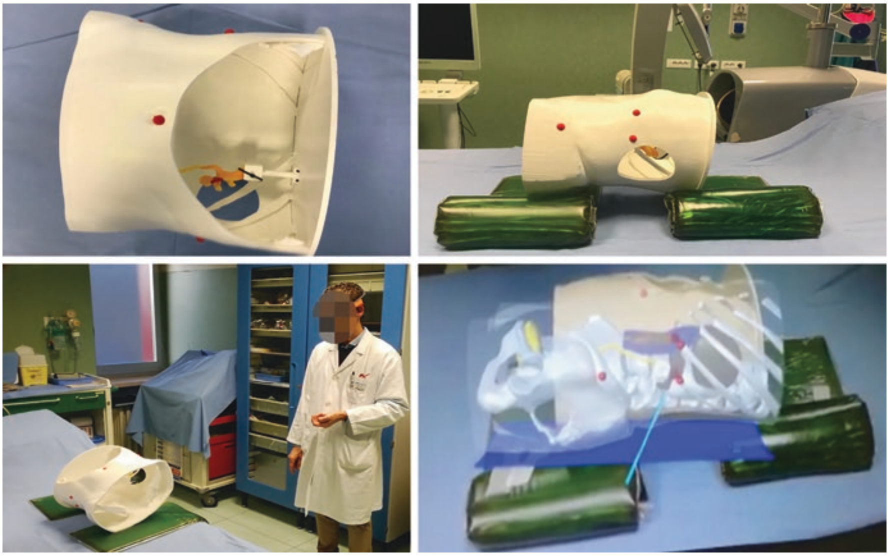

Fig. 26.4 3D printed model of the kidney affected by calyceal stone can be studied preoperatively; moreover, with the assistance of 3D Mixed Reality it is possible to simulate the needle route

Laparoscopy and Robotics

Minimally invasive laparoscopic or robot-assisted procedures can be very challenging for the surgeon and consequently dangerous for the patient. For these reasons thorough planning is fundamental, in order to minimize the risk of unexpected adverse events.

Porpiglia et al. realized hyper accuracy three-dimensional (HA3D™) reconstructions. These models clearly visualize the vascular anatomy and the intraparenchymal vessels supplying the tumor. Based on these 3D images, it was possible to simulate selective clamping and calculate the corresponding rate of ischemized parenchyma. This instrument was particularly useful during robot-assisted partial nephrectomy (RAPN), proving to be effective in avoiding global ischemia of the kidney [21].

Similarly, Wake et al. printed 3D models prior to kidney and prostate surgery in order to educate patients about their own clinical case pre surgery. Through a Likert scale survey assessing questions, such as "How would you rate your understanding of your cancer/disease?", the authors investigated the patient's perception, finding positive feedback [22].

Focus on Andrology

There is little experience about andrological surgery and simulation in the literature, given the type of surgical interventions and the kind of diseases faced (mainly benign). A pilot study by Pavone et al. described the use of a three-dimensional model for planning corporoplasty for Peyronie's disease. After injecting intracavernous Alprostadil, up to 50 pictures of the groin area were taken and, subsequently, a 3D model was obtained. The model was modified using Blender software (Blender Foundation, Amsterdam, the Netherlands), obtaining a 3D virtual representation of the penis after surgery. Using a dedicated Likert scale, the investigators evaluated the usefulness of these models, administering questionnaires to both patients and surgeons during counseling and surgical planning, showing that virtual models represent a highly appreciated feature during these crucial phases [23].

26.4.2.2 3D Printed Model & Planning

Endoscopy of the Lower Urinary Tract

No relevant experience has been found for this topic.

Stones and Ureteroscopy

There are several reports in the literature concerning the use of 3D printed models for the planning of renal stone treatment, mainly for PCNL. As reported by Bianchi et al., a 3D printed model, created following the steps explained in the initial paragraphs of the chapter, can be used to study the patient's anatomy and to simulate which renal calyx should be punctured in order to reach a stone-free status [24]. A Chinese team of endourologists [25] developed a patient-tailored 3D printed kidney model in order to achieve this goal in patients with complex staghorn stones. Despite the limited number of patients recruited, the results were promising. A correlation between postoperative results and the corresponding simulation was found, and the simulation influenced the choice of surgical approach.

Laparoscopy and Robotics

Golab et al. reported a complex case of a renal mass with an atrial mass/thrombus which was approached with a multidisciplinary strategy: the realization of a custom 3D model studied during the planning phase, has been evaluated as very useful by surgeons [26]. Komai et al. described the so-called 4D surgical navigation system, which takes advantage of patient-tailored 3D models. Thanks to modern 3D printers, the lesion was detachable from the kidney model, giving the surgeon the chance to see the kidney before and after the lesion's removal (4D vision) prior to surgery [27].

Porpiglia et al. [28] and Shin et al. [29] have shown how the realization of printed 3D models improves the accuracy of surgery during robot-assisted radical prostatectomy. The ability of the aforementioned reconstructions to show the nearness of the lesion to the prostatic capsule was clearly stated, and the surgeons were reported to have had a better perception of the lesion location. Preliminary findings reported that the use of this technology was associated with better oncologic outcomes.

Focus on Renal Transplantation

There is little data in the literature concerning renal transplantation and surgical training. Uwechue et al. printed a synthetic 3D cradle of an anatomically correct pelvis starting from the recipient's CT images. The model included the whole pelvis, the vertebral column (L4 – coccyx), abdominal vasculature, and iliac vessels (internal iliac vessels terminating 3 cm distal from their origin). The authors used cadaveric donor vessels (when spared during the harvesting procedure) and practiced the execution of the vascular anastomosis, which was consequently tested by injecting intravascular saline solution. The model proved to be useful and the authors hope for a future in which each patient will have a tailored model, preoperatively used to practice each procedure [30].

Kusaka et al., similarly, printed models of the donor graft and of the recipient's pelvis, allowing the surgeons to simulate and practice laparoscopic renal transplantation, particularly the most challenging phases (e.g., vessel anastomosis). These models were also used as an intraoperative surgical navigator, increasing the surgeon's perception of the patient's anatomy [31].

26.5 Other Applications of 3D Modeling

26.5.1 Diagnosis and Patient Counseling

Patient counseling is fundamental for the success of a medical act, but the communication is not always smooth, since the surgeon must often face limits given by the patient's scholarship and cultural extraction. Images, on the other hand, are straightforward, easier to comprehend, and have the power to communicate an idea in a blink of an eye.

As previously said, 3D models (whether virtual or printed) provide an accurate and comprehensive anatomical representation of the organ/lesion under examination. While in some cases the diagnosis is evident (e.g., contrast-enhanced exophytic renal mass), in others it can be tricky, forcing radiologists and urologists to use further diagnostic instruments. One of these is three-dimensional reconstruction, which represent a useful tool to focus on determined characteristics, which will help the physicians to discriminate the nature of suspect lesions (e.g., renal neoplasm versus calyceal UUTUC).

As reported by Porpiglia et al. [32] and Checcucci et al. [33], both patients and surgeons find the use of virtual and printed models appealing and useful. For example, during the 2017 Edition of Techno Urology Meeting (TUM) held in San Luigi Gonzaga Hospital (TO), specific questionnaires concerning the 3D models were administered to patients. The results were satisfying both from the surgeon's and the patient's point of view.

Other authors, such as Atalay et al. [34], underlined the importance of 3D models in this preoperative phase: the author, by administering questions to patients, demonstrated how the overall comprehension of the anatomy, disease, treatment and related complications was improved by up to 64% compared to baseline tests, confirming the great communicative power of 3D models.

26.6 Conclusions

Simulation plays an essential role in every scientific discipline and has its roots and origin in the birth of scientific thinking itself.

In our times, medical and, in particular, surgical disciplines are increasingly characterized by the use of diverse and complex technologies, which need to be fully understood by the operators. In this scenario, surgeons are often forced to learn and master different techniques, increasing the risk of errors. On the other hand, expert surgeons face clinical cases of extreme difficulty, which challenge the work and knowledge they have gained over the years. To minimize the risk of adverse events, simulation covers an important role and offers the chance to practice difficult cases in a safe environment thus potentially avoiding complications. Thanks to the integration of the latest technologies, such as the 3D-technology, trainees can learn faster, experts can adapt their surgical strategy, novelties can be developed and integrated into clinical practice.

In the future, with the creation of dedicated software and algorithms incorporating artificial intelligence, trainees and surgeons will be able to simulate the complete surgical procedure, recreating every scenario and thus minimizing the impact of casualty and chaos, in favor of causality and control.

Key Points

- 3D modeling represents one of the most appealing technologies of the last decades, particularly in the surgical field.
  How to create a 3D model?

- Radiological imaging (e.g., contrast-enhanced CT-scan) represents the base from which a 3D model is built.
- 3D models can either be virtual or printed.
- 3D models can be virtually displayed using a 2D screen or in a Mixed Reality, Virtual Reality, or Augmented Reality setting.
- There are three main fields in which 3D models are particularly useful, in the simulation scenario: surgical training, surgical planning, and patient counseling.
- Stone treatment, ureteroscopy, and robotics represent categories that have particular interest in the field of 3D simulation.
- Technology is covering an increasing importance: 3D models represent a popular and useful technology that will be increasingly present in everyday surgical and urological practice.

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Chapter 27
Simulation in Pediatric Urology

Yousef El-Gohary, Salahuddin Syed, Alexander M. Turner, and Ramnath Subramaniam

27.1 Introduction

Simulation in surgery is an educational technique that allows for a trainee's interactive performance in a patient-safe environment, recreating a virtual clinical scenario. It has been well established in several non-medical industries, such as aviation and the military [1].

Over the last few decades, surgical training has radically changed, with a shift away from the time-bound apprenticeship model and more toward competency-based training. The acquisition of various technical and non-technical skills has resulted in a shift away from the surgical theater and more toward the surgical skills laboratory. This is achieved through simulation-based education, which has been incorporated into all levels of surgical training. As a result, surgical skills are no longer solely acquired in the operating room, with several platforms existing to help further surgical education. These platforms include online simulation, virtual reality trainers, basic surgical skills courses, and laparoscopic bench trainers.

Traditional training of apprenticeship in the operating theater and at the patient's bedside is dependent on the length of time spent in the hospital setting. However, work-hour restrictions for surgical trainees in North America and the implementation of the European Working Time Directive in Europe in 2009 have arguably presented a set of new challenges with reducing exposure to index cases for surgical trainees and the loss of continuity of care [2]. It is argued that simulation in surgical education helps trainees acquire the necessary skills while working with smaller case volumes, circumventing these work-hour restriction constraints [1, 3]. Simulators are available at any time to be used, making them flexible for training, unlike patient exposure.

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Pediatric urology is one of the first subspecialties to embrace advanced surgical technology in retroperitoneoscopic, laparoscopic, and robotic surgery. However, there are a few simulation tools catered to pediatric urology. Technical skills acquisition is vital since the suture material used is finer, the target organs are more delicate and, most important of all, the surgical spaces are smaller to work in. Therefore, simulation training for minimally invasive surgery in pediatric urology is critical as it has been at the forefront of new emerging technologies for endourological and invasive surgical procedures [4].

27.2 History of Simulation Training in Laparoscopic Surgery

The gradual shift from open to laparoscopic surgery in the 1990s represented a giant leap in surgical innovation and advancement. This was as a result of a strong desire among surgeons to improve patient outcomes and patient safety. However, this presented its own set of unique challenges to the surgeons since laparoscopic surgery involves an entirely different set of skills than open surgery. This included the loss of tactile feedback, altered hand–eye coordination, and the need for fine motor skills since laparoscopic instruments amplify small movements. These skills can be achieved through simulation before patient contact [5]. The first cystoscopes were used on humans through the abdominal wall, and a report was published in 1910, but it was not until 1987 when the first video laparoscopic cholecystectomy was done [6]. This early, slow pace of laparoscopic evolution was primarily related to the limitations of technology and training. The single most essential technological advancement for complex laparoscopic surgery would be the advent of video laparoscopy. The Society of American Gastrointestinal and Endoscopic Surgeons (SAGES) recognized the value of laparoscopy surgery. As a result, they launched in 1997 the Fundamentals of Laparoscopic Surgery (FLS) program in response to the need for formal education in the underlying principles and basic skills of laparoscopic surgery. FLS is a comprehensive web-based education module that includes a hands-on skills training component through laparoscopic bench-trainers and assessment tools designed to teach physiology, fundamental knowledge, and technical skills required in basic laparoscopic surgery [7–9]. Before the FLS program, learning laparoscopic surgical techniques was a haphazard affair for many surgeons.

The American College of Surgeons cosponsored the FLS program in 2005. Since then, more than 30 countries have purchased the FLS online didactics and the FLS Training System, and surgeons from more than 20 countries have taken the FLS exam [9]. In 2008, the American Board of Surgery mandated that all general surgery residents seeking board certification pass the FLS exam to be eligible for the general surgery qualifying exam [9]. As a result, the FLS has created a standardized validation of surgical training for surgical residency education in North America and has been shown to predict operative performance [10]. SAGES then introduced the Fundamentals of Endoscopic Surgery (FES), a program modeled after FLS training in endoscopy [11]. It is now also mandated for surgical trainees to undertake it before their board certification in 2018 [11]. Both the FLS and FES programs serve as models for creating simulation-based tools to teach skills and assess surgical trainees' competency, improving the quality of surgical education, and improving patient safety.

27.3 3D Printing

The most common pediatric urology procedure requiring intracorporeal suturing is the pyeloplasty. This specific skill set can be addressed through laparoscopic bench-trainers and programs such as the FLS [5]. However, other technologies have emerged to simulate tissue handling and manipulation in the form of three-dimensional (3D) printing in urological training and have gained momentum [3]. The anatomical model is acquired with CT or MRI imaging and then constructed as a 3D model through layer-by-layer technique, using various materials. This model has been used for laparoscopic pyeloplasty, and for other pediatric urologic procedures such as percutaneous nephrolithotomy, partial nephrectomy, and ureterovesical anastomosis [3]. A 3D simulator printing and silicone model for laparoscopic pyeloplasty was developed by Cheung et al. and demonstrated validity between pediatric urology fellows and their consultants (Figs. 27.1 and 27.2) [12]. The same model has been proposed for pediatric urology trainees to perform partial and radical nephrectomies [12].

Another standard procedure in pediatric urology is transurethral catheterization. However, one of the most common causes of urethral trauma is iatrogenic injury from improper catheterization [13]. Incorrect Foley catheter insertion can also lead to urinary tract infections, leading to urosepsis and septicemia. Simulation through a 3D-printed model offers a more realistic manipulation of the mobile silicone external genitalia [14]. It is a useful tool, particularly for junior doctors and undergraduate medical students, providing realistic simulation with haptic feedback. This

Fig. 27.1 3D printing and silicone pyeloplasty model. The overlying peritoneum (**a**) marked with the renal pelvis exposed using an FLS trainer (**b**) with anastomosis done intracorporeally (**c**) (copyright permission from Journal of Surgical Education)

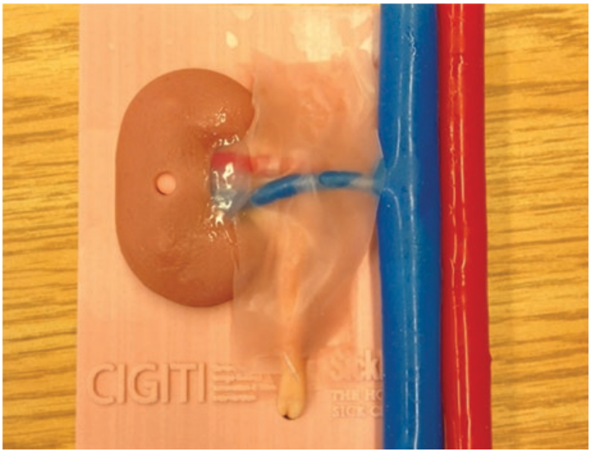

Fig. 27.2 A silicone rubber kidney phantom created by combining 3D printing with patient imaging such as MRI, 2D, and 3D ultrasound (copyright permission from Journal of Surgical Education)

allows the trainee to have increased confidence with transurethral catheterization, without the added stress of performing it for the first time on a real patient.

27.4 Virtual-Reality Simulation

The utilization of robotics in pediatric urology is increasing, with many considering robotic surgeries to be one of the next evolutions in minimally invasive surgery. Several surgical procedures in pediatric urology utilize robotic surgery, such as pyeloplasty, ureteric reimplantation, Mitrofanoff creation, and heminephrectomy [15]. Some have even shown how robotic-assisted pediatric laparoscopic pyeloplasty consistently produced shorter operative time than conventional laparoscopy [16]. The most appealing aspect of robotic technology lies in its enabling capabilities, allowing surgeons to perform procedures that would outperform traditional laparoscopic instrumentation abilities. The improved dexterity and advanced suturing skills make it very valuable to any surgeon, especially in long and complicated surgical tasks. With technological advancement, smaller ports, smaller instruments, smaller robots, and an increased range of motion, it is only a matter of time before it becomes standardized teaching among pediatric surgical trainees. The downside is the cost-effectiveness of using the robot with little data to support its being entirely cost effective. To help drive the cost down, pediatric urologists can reduce console time through structured training and simulation models with a dedicated robotics team and increased use by multiple other subspecialties [15]. The current era of robotic surgery closely mirrors what laparoscopic surgery underwent in the early twentieth century. It will soon follow suit with both FLS and FES in terms of a standardized and validated robotic training curriculum for surgical trainees seeking board certification in surgery. The evolution of training and the future development of novel technological advances will ensure this.

Since most institutions cannot afford a robot dedicated to training, it has been postulated that the best method to train the future generation of robotic surgeons is through virtual reality simulators [17]. This is achieved through the computer-based platform and artificially generated virtual environments that provide statistical feedback to the surgeons. The most commonly used system is the da Vinci® Surgical System from Intuitive Surgical, Inc., and it consists of two main components; a master console and a slave robot [17]. The master console is manipulated by the surgeon, who controls the slave robot to perform the necessary motions on the patient. There are multiple virtual reality trainers available for robotic platforms, including SEP Robot (SimSurgery, Oslo, Norway), Robotic Surgical Simulator (RoSS; Simulated Surgical Systems, Buffalo, NY), dV-Trainer (Mimic Technologies, Inc., Seattle, WA), ProMIS® (Haptica, Ireland), and da Vinci Skills Simulator® [17, 18]. All of these can be used to certify in robotic surgery and are validated for pediatric urology training [19]. The downside to these virtual reality simulators is that they only test generic tasks such as tissue manipulation, suturing, hand–eye coordination, dissection, and knot tying. Training for specific procedures would be a bonus to enable the performance of critical steps. Recently, a virtual reality simulator training specifically for robotic-assisted radical prostatectomy has been developed as a new tool in surgical education [20]. This was done utilizing RobotiX Mentor® (3D Systems; Simbionix Products, Cleveland, OH, USA), a robotic surgery virtual simulator that has been developed to train surgeons using the da Vinci® Surgical System (Intuitive Surgical, Sunnyvale, CA, USA) [20].

One of the crucial steps to performing robotic procedures in children involves correct docking of the robot, port placement, and arm positioning [15]. A learning curve of around 30 cases is needed to demonstrate a statistically significant reduction in time between learning and maintenance phases for robotic-assisted pediatric urological procedures, thus helping drive the cost down [21]. This includes correct port site placement, as demonstrated in the following figures (Figs. 27.3, 27.4, and 27.5).

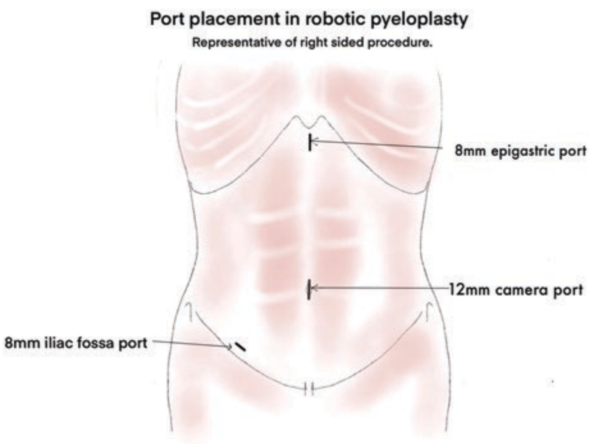

Fig. 27.3 Robotic port placement for a right pyeloplasty. If performing a left pyeloplasty, then the 8 mm iliac fossa working port is placed in the left iliac fossa. For patients less than 2 years of age, the iliac fossa port is placed more medially toward the midline. The same port positions can be used for a hemi-nephrectomy

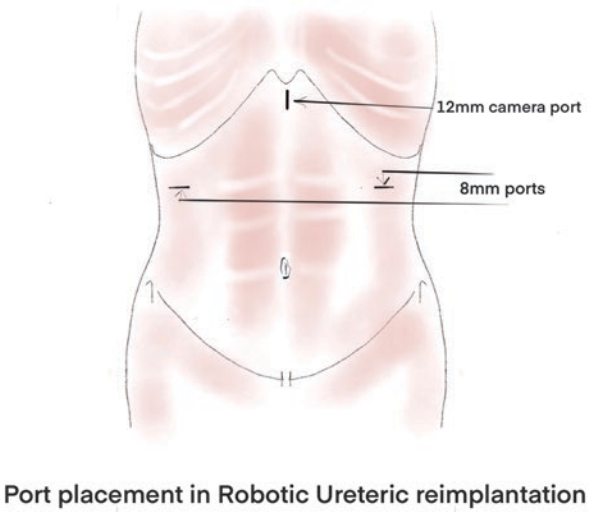

Fig. 27.4 Robotic port placement for ureteric reimplantation

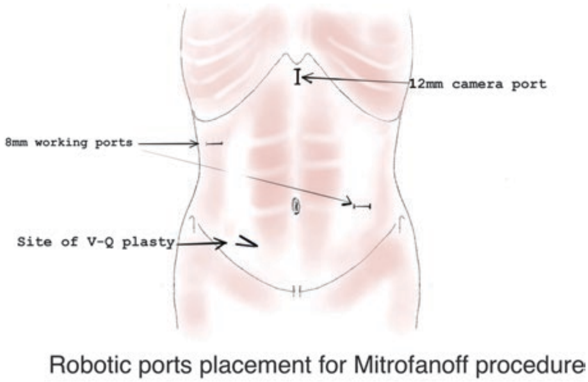

Fig. 27.5 Robotic port placement for Mitrofanoff creation with the exit site at the V-Q plasty mark

Chowriappa et al. looked at urethra-vesical anastomosis using a virtual simulator, randomizing the trainees into two groups: an intervention arm performing the procedure-based virtual reality training and a control group. The virtual reality training group achieved better performance and higher scores than the control group [22]. This was also supported by another group, where they showed that 5.5 hours of simulation training in the urethra-vesical anastomotic virtual reality model led to significant learning curve improvements for both expert and novice surgeons [23].

27.5 Online Simulation

An online educational module has been developed to help harmonize all surgical theater staff members, including the consultant surgeon, urology trainee, circulating nurses, and surgical technicians, during pediatric robot-assisted laparoscopic pyeloplasty. This was initiated because performing pediatric robotic surgeries effectively and efficiently requires a unified team approach. The module is delivered via computer-enhanced visual learning (CEVL), allowing the user to recognize when they have acquired basic knowledge to be functional in the surgical theater [24]. Providing all surgical theater staff members a shared online interactive learning to use prior to, and concurrent with, the surgical case will allow effective teamwork and, therefore, enhance patient care. This has been similarly applied to create an online learning interactive training in endoscopic Botox injection for pediatric urology fellows which included a narrated video on the Botox reconstitution process [25].

27.6 Procedure-Based Simulation and Low-Cost Options

Procedure-based simulation allows trainees to perform parts of or an entire surgical procedure in a simulated environment. Ideally, this is performed on a cadaveric or animal model, but this is limited due to ethical and financial constraints. As a result, synthetic bench models have been developed to mimic a specific organ. One such example is the laparoscopic ureteral reimplantation model developed by Millan et al. in 2018, employing the Lich–Gregoir technique for pediatric ureteral reimplantation [26]. Using reusable and disposable materials, trainees could practice extra-vesical ureteral dissection, followed by mucosa exposure after detrusor division, followed by reimplantation of the ureter into the new tunnel, and finally reapproximating and suturing of the detrusor muscle (Figs. 27.6 and 27.7) [26]. Surgical participants in the ureteric reimplantation model perceived benefit for a technique that is not commonly employed [26].

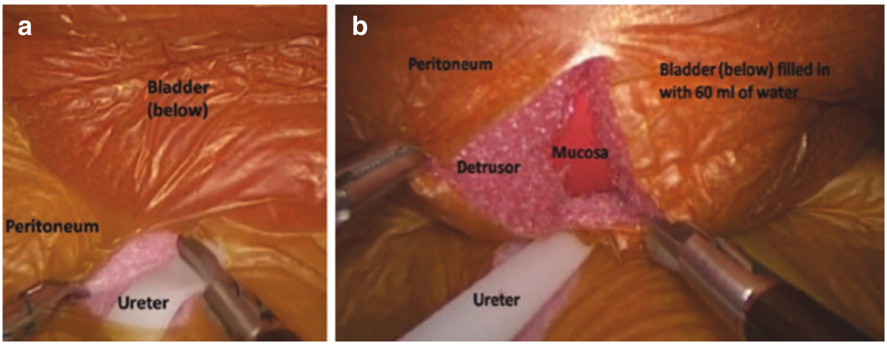

Fig. 27.6 Laparoscopic ureteral reimplantation model employing the Lich–Gregoir technique. The peritoneum (IOBAN™ drape) is incised to identify the distal ureter, isolated and dissected toward the vesicoureteral junction (**a**). The detrusor muscle (ellipsoidal pocket of polyurethane foam) is divided with scissors until the mucosa (water balloon) is exposed (**b**) (copyright permission from Journal of Pediatric Urology)

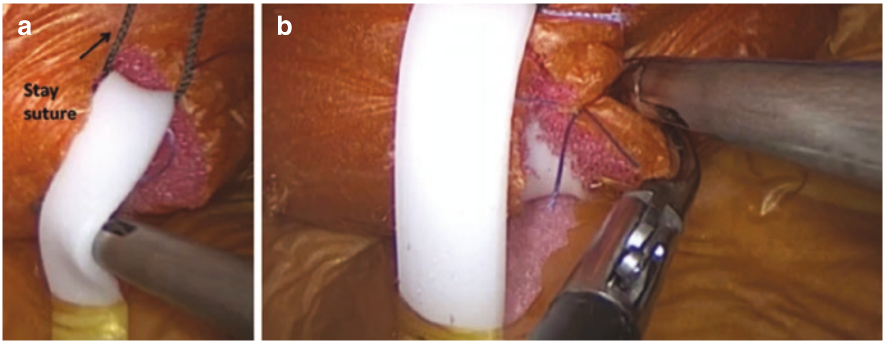

Fig. 27.7 Laparoscopic model for the Lich–Gregoir technique. After completing the dissection, a stay suture is placed around the ureter toward the top of the bladder. The ureter is introduced into the newly created tunnel (**a**). The detrusor muscle is re-approximated with three or four interrupted intracorporeal stitches (**b**) (copyright permission from Journal of Pediatric Urology)

The advent of laparoscopic pyeloplasty has led to a reduced caseload of open surgery for children older than 1 year of age. Open surgery for the ureteropelvic junction poses unique challenges due to smaller workspaces, more delicate sutures used, and the need for increased surgical dexterity. As a result, a low-cost model was developed by a group in France for dismembered Anderson–Hynes open pyeloplasty [27]. The simulator's construction requires the following: A4 Kraft envelopes, 60 mL catheter tip syringe filled with 30 mL of air, 260 modeling balloon (mimicking the ureter), 11-inch party balloon (to mimic a dilated renal pelvis), strong glue, permanent marker, and tape (Fig. 27.8). The group showed face validation of this low-cost simulator for open dismembered pyeloplasty (Fig. 27.9). The authors proposed this is an educational tool for ureteropelvic junction teaching and training [27]. This model is very appealing compared to the laparoscopic pyeloplasty simulation module (Simulab Corporation, Seattle, WA), which costs $650, or an animal simulator for a skills laboratory, where the costs can be prohibitive if a veterinary technician and support staff are included [27]. Other authors have described using porcine bladder as a simulator for laparoscopic pyeloplasty to train single-knot running suture anastomosis [28]. The appeal of this simulator is that it provides a realistic simulation without resorting to live animals.

Another model for pediatric urology trainees is the suprapubic catheter insertion simulation training model [29]. Suprapubic catheter insertion is a basic skill that urology trainees should be adept with. The model has three anatomic parts: the bladder, the anterior abdominal wall, and the housing abdominal box. A standard party balloon filled with tap water is used to represent the bladder, over which a strip of Mefix tape (Molnlycke Health Care) is placed over which remains adherent when wet, and prevents the bladder (balloon) from "popping" during dilator peel-away sheath placement, the anterior abdominal wall is replicated by layering a household sponge, a 3-layer square of Transpore by 3M (rectus sheath) and another sponge (abdominal wall fat). The housing box is a plastic container with a clip lid. A circular hole is cut out of the lid to allow access to the bladder (Figs. 27.10 and 27.11).

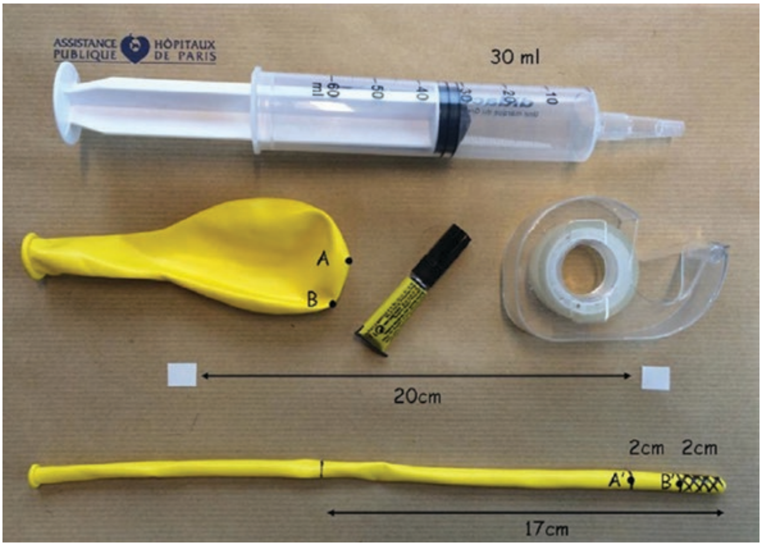

Fig. 27.8 Components of a low-cost simulator model for dismembered Anderson–Hynes open pyeloplasty. This includes: A4 Kraft envelopes, 60 mL catheter tip syringe filled with 30 mL of air, 260 modeling balloon, 11-inch party balloon, strong glue, permanent marker, and tape (copyright permission from Journal of Surgical Education)

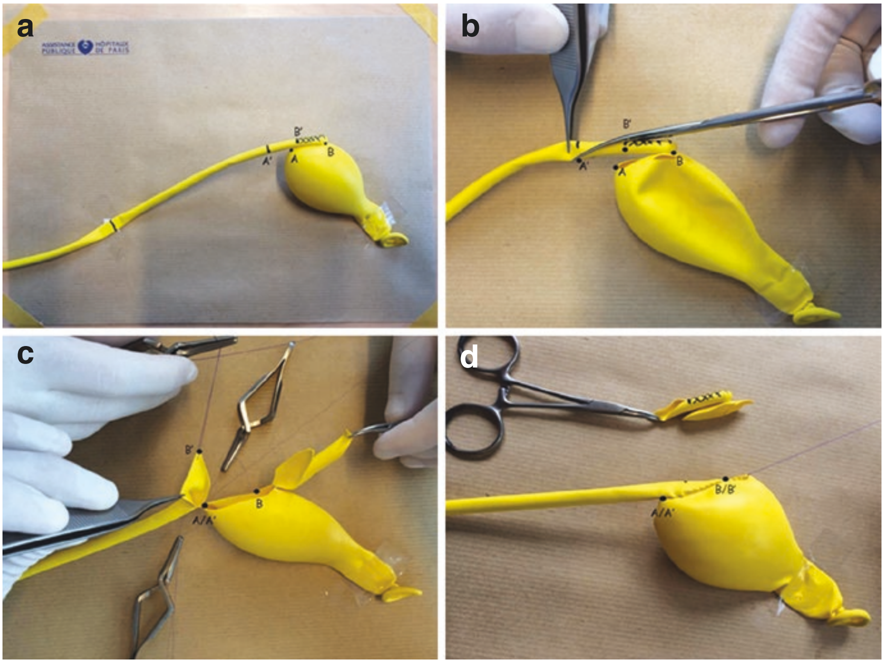

Fig. 27.9 Main steps of the dismembered Anderson–Hynes open pyeloplasty procedure using cheap assembled components. Pyeloplasty model assembled (**a**). Ureteropelvic junction resected (**b**). Anderson–Hynes pyeloplasty procedure (**c**). Final result after pyeloplasty (**d**) (copyright permission from Journal of Surgical Education)

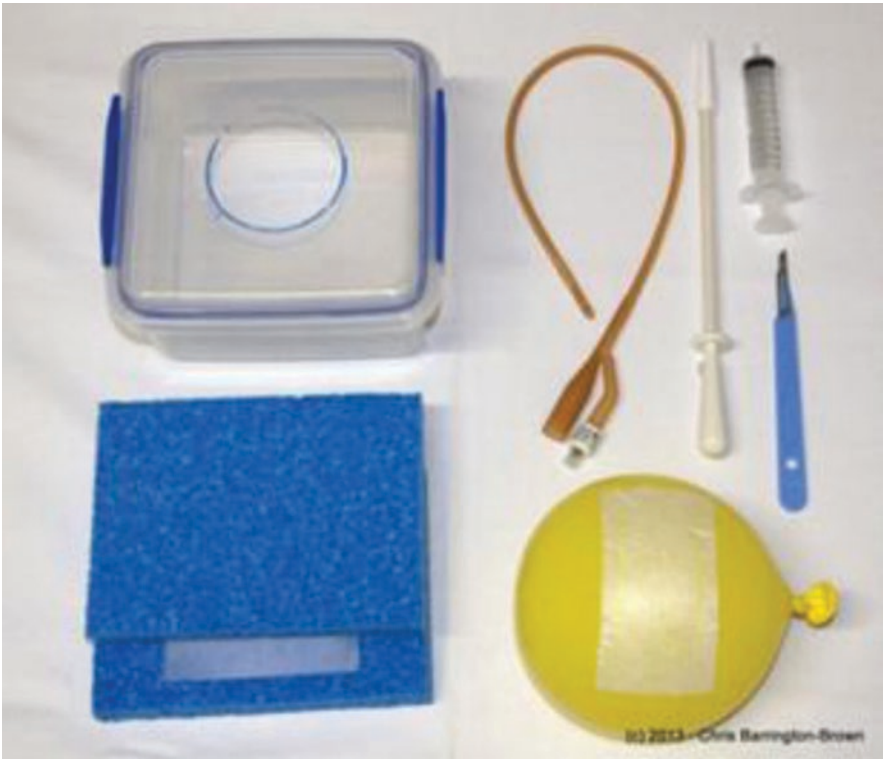

Fig. 27.10 Components of a low-cost simulator model for suprapubic catheter insertion model. This includes: Standard party balloon filled with tap water (as the bladder), a strip of Mefix tape (Molnlycke Health Care), 15-blade knife, 12F Lawrence Add-a-Cath (Femcare-Nikomed) , plastic lid box, 3-layer square of Transpore by 3M (rectus sheath), household sponge, and a Foley catheter (copyright permission from Urology journal)

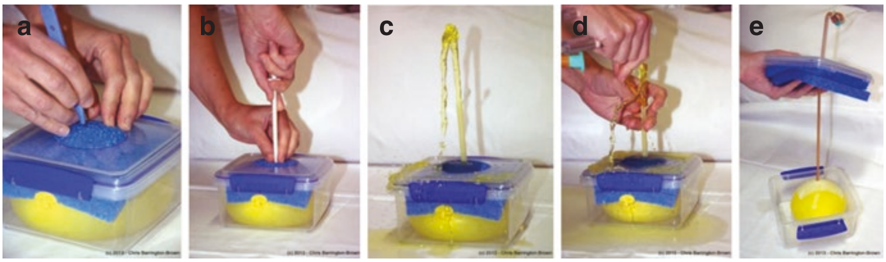

Fig. 27.11 Suprapubic catheter insertion procedure using a low-cost simulation model. Scalpel incision (**a**). Insertion of dilator introducer sheath (**b**). Flow of urine through sheath (**c**). Insertion of catheter through sheath (**d**). Lid removed demonstrating Foley catheter in bladder (**e**) (copyright permission from Urology journal)

Endoscopic correction for vesicoureteric reflux is a procedure where the operator has one chance to get the procedure right. Consequently, trainees can be excluded from this activity in favor of the most experienced operator. Soltani et al. validated a porcine bladder simulator specifically for training and assessing this procedure [30]. The tool can improve trainees' performance in carrying out the procedure and allows a greater understanding of this technical procedure, prior to experience in patients.

The current Accreditation Council for Graduate Medical Education (ACGME) urologic residency requires a minimum of ten percutaneous renal endourology procedures performed in order to complete residency training successfully [31]. As a result, an abdominal phantom model for ultrasound-guided percutaneous renal access has been developed [31]. A skill that is needed to practice is percutaneously placing a needle into the kidney to facilitate nephrostomy tube placement, percutaneous nephrolithotomy, renal biopsies, and percutaneous ablation of renal masses.

27.7 Hybrid Simulation

Although surgical simulators provide trainees with structured opportunities to assess technical skills, they do not address non-technical skill objectives. To provide trainees with the exposure necessary to develop such interpersonal communication skills training, hybrid simulation models have been developed, which involve combining two forms of simulation, such as pairing of part-task trainer with simulated patients [32]. The aim is to simulate real-world clinical scenarios' complexity, enabling the learner to be assessed on multiple skills concurrently. Part-task trainer simulators can be synthetic, cadaveric, or animal models that simulate part of a surgical intervention [18]. It has been used for urology residents in-training for cystoscopy and stent manipulation [33]. The patient vital signs are simulated and manipulated during the evaluation through the use of SimMan (Laerdal Medical Canada Ltd., Toronto, Canada), while video monitoring and assessing the urology trainee's technical performance for cystoscopy and stent manipulation along with their interaction with the live standardized patient in real-time [33]. Different clinical scenarios can be assessed, such as interaction with a nurse-assistant during a procedure or a stuck stent that is unable to be removed. This hybrid cystoscopy model represents a good simulation of a real-world procedure and will gradually replace time-based surgical training.

Similarly, a laparoscopic nephrectomy model has been developed to assess a urology trainee's capacity to evaluate their communication and management skills in a scripted critical event during surgery, such as renal vein injury during hilar dissection [32]. The hybrid simulation uses a novel kidney surgical model and a high-fidelity mannequin simulator. These models help address communications failures that can arise in a high-stake environment such as the operating theater and help avert significant surgical morbidity or even mortality.

27.8 Summary

Pediatric urologists have been at the forefront of surgical technology in the form of retroperitoneoscopic, laparoscopic, and robotic surgery. Now they have embraced the surgical evolution in surgical training through simulation with the ever-growing constraints in surgery, including work-hour restrictions and the litigious atmosphere. Surgical simulation can further train novice surgeons by allowing the acquisition of surgical skills with ease of repetition, the advancement of learner-centered skills, and flexible training hours, all in a low-risk, stress-free environment. The technological armamentarium of simulation platforms have shown validity, help decrease surgical errors, and shorten the learning curve to technical proficiency. The field of robotic surgery is advancing fast as new technologies are emerging and can potentially advance surgery to a new level. We are closely monitoring the fast development of this field with great excitement.

Key Points

- Pediatric urologists are at the forefront of surgical technology and have embraced the surgical evolution in surgical training through simulation.
- Surgical skills are no longer solely acquired in the operating room.
- Shift away from the time-bound apprenticeship model and more toward competency-based training.
- Surgical simulation allows for the acquisition of surgical skills with ease of repetition and flexible training hours in a low-risk, stress-free environment.
- Surgical education platforms include online simulations, virtual reality trainers, and laparoscopic bench trainers.
- Simulation helps trainees acquire surgical skills by circumventing the work-hour restriction constraints.
- Three-dimensional printing has gained momentum for transurethral catheterization, laparoscopic pyeloplasty partial and radical nephrectomies in children.
- Synthetic simulation bench models available include laparoscopic extravesical ureteral reimplantation, open Anderson–Hynes pyeloplasty, and suprapubic catheter insertion.
- Hybrid simulation models address non-technical skills and communication failures in the surgical theater averting significant surgical morbidity.

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Chapter 28
"I Know How to Help Trainees but …:"—How to Incorporate Implementation Science in Design and Delivery of a Simulation Program

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28.1 Introduction

This chapter will outline the steps that need to be considered for the effective implementation of a simulation program. Evidence-based Medical Simulation practice is still in its infancy; unfortunately, most educators follow a "suck it and see" approach in simulation program development and are learning and designing as they go along [1]. Introducing a simulation program is a journey starting from an idea to a full-fledged practice. Setting up a simulation program can be a complex task involving several small components. The success depends on the safe completion and proper alignment of all these tasks. The use of project timelines and deliverables will help develop programs that are able to meet their educational targets, are sustainable beyond their initial inception, and are also scalable without over-reliance on their initial developers.

Simulation-based education (SBE), although a multi-component, multi-faceted process, is accepted as a successful intervention for the preparation of healthcare

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personnel. As the complexity and dynamic nature of the healthcare environment increase, today's trainees are expected to possess not only specialty-specific technical skills but also a wide range of non-technical skills [2–4]. There is increasing pressure to establish the value of SBE (costs versus benefits, or return on investment) to policymakers, training committees, patients, providers, governments, funders, research sponsors, and other healthcare stakeholders. Due to the intricacy of the process, a structured trainee-centered design and successful implementation of a simulation-based program require evidence-based practice (EBP).

Although the literature generally agrees on the effectiveness of SBE, there is a growing appreciation that a "*one size fits all*" methodology ends in less effective training program designs, and hence individual variances among trainees and the local settings should be taken into consideration in SBE design and use. There is some acknowledgement that the full potential of SBE has not been investigated possibly due to the lack of standardization in the approach to SBE and failure to apply consistently best practices in the design and implementation of SBE programs [5–7]. The design of simulation-based experiences incorporates best practices from adult learning, education, instructional design, clinical standards of care, evaluation, and simulation pedagogy [8–12]. A standardized simulation project provides a framework for developing effective simulation-based experiences. Overall, the literature supports the view that successful SBE requires a multidisciplinary approach to the design, development, delivery, and evaluation of simulation-based learning experiences for trainees.

While the multi-disciplinarity of SBE development and delivery are not contested, the field is yet to make use of the newly emerged field of implementation science, and more broadly, implementation research methods, techniques, and measures. The use of standardized and evidenced implementation approaches can support the delivery and sustainability of SBE, if applied suitably. To our knowledge, the field of SBE has not yet integrated such approaches. Our aim in this chapter is to start addressing this gap. We first define implementation science and introduce some basic concepts of the field. We then present a case study of a complex SBE, implemented at a national scale in the UK, to illustrate the applicability and added value of an implementation science perspective on SBE. Our ultimate goal is to make implementation concepts accessible to clinical and educational colleagues so they can apply them to the design of future SBE programs.

28.2 What Is Implementation Science?

Implementation science is the study of methods to promote the systematic uptake of evidence-based programs and practices into a health setting and thus to improve the quality and effectiveness of intervention delivery [13]. Fixsen et al. [14] defined the field as "a specified set of activities designed to put into practice an activity of known dimensions." Bartlett and Ghosal [15] studied various industries and reported that "the issue was not a poor understanding of environmental forces or inappropriate strategic intent. Without exception, they knew what they had to do; their difficulties lay in how to achieve the necessary changes.” Miller [16] also noted that businesses fail to implement 70% of their new planned initiatives. The field, therefore, extends well beyond health and healthcare as such.

Implementation science is an offshoot of the evidence-based medicine (EBM) movement. Proponents of EBM examined why some robust evidence-based interventions collapsed trying to get off the ground, why some were not sustainable, and why some interventions started well but quickly lost momentum when applied clinically outside research settings. Effective implementation bridges the gap between research and practice by assisting to confirm that EBP’s are validated in “controlled” settings to achieve similar results in the “real-world.” Effective and efficient implementation is important as designing successful clinical intervention SBE programs for clinical trainees is only the first step: transferring and sustaining these programs in real-world settings is an extensive and multi-dimensional process. Furthermore, having an implementation framework allows the use of a structured guide for successful implementation practice, separation of different stages of the implementation process, and provides data-driven decision-making continuously to improve the program at subsequent stages.

A major element of implementation science is the focus on what has been termed in the literature “implementation strategies” [17, 18]. These are methods or techniques that can be used to support and enhance the implementability of an EBP or SBE—or other intervention of interest. Implementation strategies need to be considered at the early stages of the implementation; then subsequently reviewed and potentially revised as the implementation matures; and on an ongoing basis as an EBP continues to be delivered, i.e. reaches the stage of sustainable delivery [19]. The currently most established framework of implementation strategies available for use within health settings is the Expert Recommendations for Implementing Change (ERIC) taxonomy. The ERIC framework proposes 9 different categories of strategies that can be used to support implementation—as follows [17]:

- Use of evaluative and iterative strategies, e.g. audit and feedback
- Provide interactive assistance, e.g. offer facilitation or supervision
- Adapt and tailor, e.g. promote adaptability of a new program
- Develop stakeholder relationships, e.g. identify champions and opinion leaders
- Train and educate stakeholders, e.g. offer training sessions and develop educational materials
- Support clinicians, e.g. redesign job plans to allow dedicated time for program implementation
- Engage patients, e.g. inform and involve patients in program support
- Utilisze financial strategies, e.g. offer incentives for implementation
- Change infrastructure, e.g. make change/implementation mandatory

Not all strategies are to be used at all times (in fact, this is not feasible). However, the use of multiple strategies rather than a single one is more likely to address more of the potential implementation barriers, hence it is advised.

Currently, institutional training programs, including simulation laboratories, are under scrutiny for return on investment, or costs versus benefits. Policymakers and other stakeholders desire more certainty about expected improvements in provider performance and clinical outcomes linked to SBE. To fully realize the benefits of SBE, an evidence-based implementation is required, and some policymakers have developed collaborative work to explore suitable methods to transform implementation evidence into practice. There is a growing body of research that shows the usefulness of implementation science in education [20], new health technologies [21], and child health [22]. Therefore, SBE implementation matters and a suboptimal approach can be expensive, as stated by Gendreau et al. [23] "*we cannot afford to continue dealing with the business of program implementation and related technology transfer topics in a cavalier fashion*."

28.3 Implementation Methods and Frameworks

Educators may question the role of an implementation strategy for a well-established SBE in a new setting. The Medical Research Council (MRC) in the United Kingdom (UK) in 2000, proposed a framework for complex interventions for designing and evaluating complex interventions and updated it in 2008 [24] and subsequently in 2015 [25]. It is a set of guidelines highlighting four stages of intervention: development, feasibility and piloting, evaluation, and implementation which take place as an iterative rather than a linear process. The lack of theory-driven approaches to evaluation is one of the limitations that the MRC highlighted early on [26]. The field of implementation science addresses this limitation. Several frameworks have been developed in the past two decades, aiming to offer a lens to better understand the implementation and subsequently improve it (e.g., diagnose the barriers to successful implementation) or to evaluate the overall success of implementation [27]. Two examples of implementation frameworks that may be of use to educators and SBE developers are the following:

- The Consolidated Framework for Implementation Research (CFIR: https://cfirguide.org/): This framework allows a structured analysis of the drivers and barriers to successful implementation. CFIR proposes that there are five main categories of such barriers/drivers to consider: (i) the actual intervention/program being implemented, (ii) the process of implementation, (iii) the people involved in the implementation, (iv) the organizational setting of implementation (i.e., hospital or training program), and (v) the wider external context (e.g., National Health Service in the UK and the current COVID19 pandemic). Based on the framework, interview and survey questions have been developed, which can be found on the framework website and tailored for use by educators.
- The Exploration-Preparation-Implementation-Sustainment (EPIS: https://episframework.com/) framework: This framework incorporates the CFIR barriers/drivers analysis and adds a dynamic element to the implementation process—i.e., it considers it longitudinally. The early stage is that of Exploration stage (e.g., is there a real need for this program?), followed by Preparation stage (this includes the pre-

paratory work in developing and setting up the program ahead of full implementation; piloting is included here). Once Preparation stage is complete, the full Implementation stage follows (program is launched), followed finally by Sustainment stage (i.e., the future outlook and sustainability of the program). These stages are not static, but a program can move between them depending on its development, maturity, and external circumstances. This includes, for instance, a program being well-established in one training rotation (i.e., in the sustainment stage) yet only just being designed for "import" in a neighboring one (the very same program would be in the Exploration stage). EPIS helps identify the stage of implementation development and activities that need to take place to support implementation.

Further useful frameworks that address implementation elements can be found within medical education, Haji et al. [28] designed a framework for developing and evaluating research programs in SBE. This model is a synthesis of an iterative approach to designing, evaluating, and implementing SBE, stressing identification of theory and current evidence, modeling the program through piloting, and appraising the program in both research and real-life settings.

A generic outline for the implementation process was developed based on fundamental core components and includes concepts relating to the process of implementation, the intervention itself, the context, motivating factors, strategies, and evaluations [29]. The basic framework in Fig. 28.1 shows essential stages and interrelationships

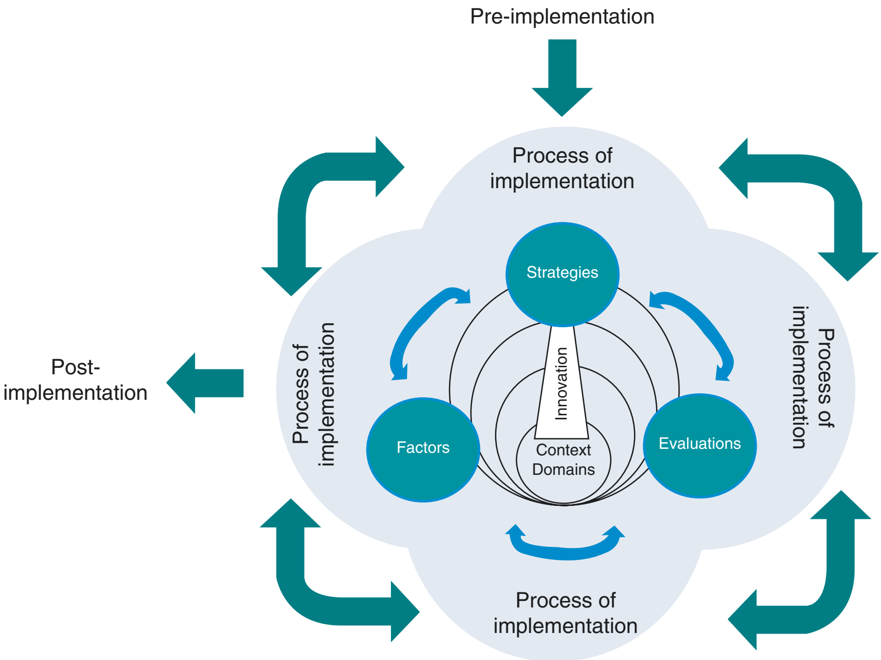

Fig. 28.1 A generic outline for the implementation process [29]

between one another. This framework incorporates key elements from implementation science and can be used with various models in conceptualizing an intervention. Several educational frameworks have been published by the General Medical Council (GMC), the Nursing and Midwifery Council, the Association for Simulated Practice in Healthcare (ASPiH), and the Higher Education Academy. Fixsen et al. [14] after an extensive review, suggested critical components of a model should be exploration and adoption, program installation, initial implementation, full implementation, innovation, and sustainability. A review on implementation science divided frameworks and models in the field into categories according to proposed intervention and the exhaustiveness of the framework [29]. Tabak et al. [30] review of 61 models and Meyers et al. [31] review of 25 frameworks both suggest common factors during the explanation of stages of implementation and their core components. Tabak et al. [30] reported 61 models for dissemination and/or implementation research with application in community- or organizational-level dissemination. Furthermore, there is a conceptual framework to measure five indexes of implementation fidelity [32]. Quantifying fidelity is one way of appraising implementation, a vital process that is just as significant as the evaluation of the program [14].

The steps to starting an SBE seem straightforward, i.e. identify needs, recruit trainers for the target group, and deliver them. However, a successful sustainable program requires an evidence-based implementation process: advanced planning, multiple stakeholders' engagement, accountability, and monitoring. Greenberg et al. [33] defined three phases of implementation—pre-adoption, delivery, and post-adoption—and recommended that they should be incorporated into intervention design. Alternatively, the Stages of Implementation Framework by Fixsen et al. [14] describe six additive stages toward full implementation of programs. These are (a) Exploration stage—existing situation assessment, (b) Preparation stage—deliberation of change, or installation phase, (c) Early (initial) implementation stage—preparation for change, (d) Full implementation stage—where change is being engaged in, (e) Innovation stage—where after practicing interventions with pure fidelity, subtle adaptations are made to best fit the user, and (f) Sustainability stage—maintenance of procedures to ensure sustainability.

Proctor and Chambers [34] reported that a few US-based training programs focus on implementation practitioners or policymakers. When programs are implemented poorly, it not only reduces the potential for helping trainees in need, but it wastes scarce resources, staff time, and funds because ineffectively implemented programs are unlikely to be very successful. Besides, an inadequately implemented SBE can mislead decision-makers into assuming that a program is unproductive when, in reality, the program might work very well if it were well-implemented. It is important to recognize that a focus on the implementation process advances research, practice, policy, and leads to a better learner experience with improved outcomes for policymakers.

Among several implementation approaches, the three-phase TeamSTEPPS™ method has proven to be an effective technique for setting up a new simulation program [35]. Phase one explores the necessity of the new program followed, by phase two looking at the set-up process, i.e. planning, education, and implementation. The site assessment phase is conducted both by self-assessment and an on-site facilitator. Establishing clear lines of communications, team leaders, and deliverables is the cornerstone of successful implementation. The final phase looks at the sustainability of a new program and how it is cascading to other sectors within and outside the institution. The success of the TeamSTEPPS™ initiative is attributed to its four core aptitudes: leadership, situation monitoring, mutual support, and communication [35].

Salas et al. [36] had a different eight-step approach, for efficient implementation of a healthcare simulation program. They emphasized the importance of creating a near-identical environment for trainees. It is essential to facilitate the repeated and deliberate practice of skills in a safe, risk-free environment, followed by learning from mistakes for effective mastery of skills. This is further reinforced by the real-world practice of such skills under expert supervision and adapting the system-based safety culture will ensure that the challenges of patient safety are overcome.

Regardless of the choice of framework, using one helps educators and implementors to plan their activities in tandem with implementation needs, stage of maturity, and wider context. We strongly advocate that any SBE implementation is supported by such a framework.

28.4 Phases of the Implementation Process

28.4.1 Exploration Phase

It has been recognized that ad hoc education sessions are not enough to develop a competent clinician [37, 38]. A key, though largely under-recognized, challenge for SBE is a decision to introduce a newly established simulation program to support a particular educational requirement in a different or existing setting.

The initial exploration phase explores several components, i.e. (a) identify the need for a new intervention, (b) recognize effective intervention, (c) ensure the intervention fits local settings and stakeholders' priorities, (d) categorize implementation barriers, (e) outline intervention package with stakeholders' input, (f) form implementation team, and (g) organize orientation meetings to distribute and discuss the intervention. It is worth considering learners' level of knowledge, understanding, and experience in addition to identifying local champions, target-setting, action planning, faculty training, providing technical support and marketing should be part of the strategy [39, 40]. It is fundamental to have backing from the training committee, simulation lead, educators, and regulatory bodies (e.g., General Medical Council). With the capacity to effectively apply and adapt learning in the face of constant environmental variations, the program planner(s) should engage all stakeholders.

For a program to be successful, the commitment of all stakeholders and the context in the new setting should be outlined. Concentrating on these two pillars should increase the likelihood of intervention uptake with fidelity [31, 41]. Fidelity is the degree to which a program is applied as planned. Safeguarding fidelity increases the chance of achieving the anticipated effects. Measuring the program adherence to content, frequency, and duration, understanding the factors of intervention complexity, facilitation strategies, quality of delivery, and participant responsiveness moderating the level of fidelity achieved and identifying essential components likely to ensure high fidelity and adaptation [32, 42].

Various frameworks have been developed to identify and engage with stakeholders. Johnson and Scholes [43] suggested that stakeholder identification can be done by assessing power against the level of interest or predictability of behavior and action considerations for each (Table 28.1). Once the stakeholders are identified, it is time to articulate the program to the implementation team to secure clear buy-in, starting with a presentation about the program to a core group to ensure their commitment, delegating specific tasks related to the implementation process, defining roles and time scale. The responsibilities in the implementation team have been described by the Consolidated Framework for Implementation Research (CFIR, see Sect. 28.3) as champions (individuals who dedicate themselves to supporting, promoting, and driving through barriers to achieve the objective), External Change Agents (technical field related professionals who may help to implement a program at multiple sites and have links with an institution or regulatory bodies), Formally Appointed Internal Implementation Leaders (individuals from within the organization doing a "part-time job" who have been formally appointed with responsibility for implementation—they may act as a champion or opinion leader) and, Opinion Leaders (educators in a program who have a formal or informal influence on the attitudes and beliefs of their colleagues concerning implementing the program). The effect of opinion leaders on promoting the interventions can vary from −6% to +25% in improving behaviors of healthcare professionals [44]. The leaders can play an important role in setting the general mood of the implementation team. When the leader decides to accept the program and commits him/herself to the success of the program, the rest of the group follows even if they were initially hesitant. Appealing stakeholders across multiple levels of an implementation ecosystem is advocated as best practice for implementation. A participatory approach involving all

Table 28.1 Stakeholder's identification can be done with assessing power against the level of interest or predictability of behavior (Adapted from [43])

		Level of interest	
		High	Low
Power	Low	Stakeholder name/group: Proactive or reactive: What is done: What more should/could be done: Keep informed	Stakeholder name/group: Proactive or reactive: What is done: What more should/could be done: Minimal effort
	High	Stakeholder name/group: Proactive or reactive: What is done: What more should/could be done: Key players	Stakeholder name/group: Proactive or reactive: What is done: What more should/could be done: Keep satisfied

stakeholders may provide a smooth landing for the program. Enid Mumford [45] highlighted the significance of the “participatory design” and the 3 levels of participation (consultative, representative, and consensus). A simulation program with multiple modules may require a good number of trainers and a collective approach.

The next important undertaking for the implementation team is to assess the local environment. This involves educational needs assessment, existing simulation courses, facilities, fit and readiness for implementation. At the exploration stage, it is vital to have a discussion with stakeholders and partners about acceptability (the perception among stakeholders that the proposed package is agreeable), adaptability (the degree to which the program can be adapted, tailored, refined, or reinvented to meet local needs), appropriateness (the perceived fit of the intervention for a local particular target group), feasibility (the extent to which the program can be implemented in a local setting), strength and quality (stakeholders' perceptions of the quality and validity of evidence supporting the acceptance that the program will have desired outcomes), trialability (the capability to test the program on a pilot in the local context and to be able to undo implementation if necessary), and cost (cost of the project and implementation). An administration workforce is not only its most valuable strength, but also is most expensive. The cost has been estimated to be as high as 70% of organizational costs [46] and a targeted systematic review on implementation of SBE reported poor cost analyses in the literature [47].

It is important to consider CFIR and Quality Implementation Framework steps before implementation, including (a) what is the reason for doing the program? (b) what learning objectives and outcomes will the program cover? The essential part of designing and evaluating a training program is to have focused learning outcomes [48]. (c) who is the target audience for the program? (d) is the program suitable for the local setting? (e) does the program address needs of the trainees, hospital, training committee? (f) are there adequate resources, skills, and motivated staff within the simulation center? (g) is the organization ready for it? (h) does the program adhere to the vision, priorities, and standards of the organization/center?

28.4.2 Preparation Phase

The information and needs identified in phase 1 should be tabulated. The program components should be developed through stakeholder consultation and feedback to focus on “what, who, where, how and when.” It is imperative to contemplate the various aspects of the trainees, training, and institute as they can influence the learning experience and training outcomes [36]. A Gantt chart can be used to plan all activities related to implementation. Important components of “what” are the program contents of any SBE. It is therefore critical to align the course contents to the curriculum [49]. In addition, a list of equipment, need for training, allocation of responsibilities, supporting staff, cost, consumables cost, course assessment, and evaluation forms should be prepared. With regard to “who” of the process involves recognizing trainers and their role. The trainer's selection should be made by matching their known area of expertise. The supporting staff (technicians, IT staff) should be given clear instructions to facilitate the learning activities. Among the trainers, course director(s), module or section lead(s), and strategy planners should be identified with well-defined roles and responsibilities. When it comes to "when" the Gantt chart will be valuable to track the progress of the implementation process. Given the complexity of SBE, questions should be considered: Is the pilot project involve many technical risks? Are there too many things to learn? Is there a plan to share and discuss data from the pilot project?

To prepare for the implementation of the pilot program, the team needs to determine when and where the implementation would take place. The "knotworking" has been described as a crucial model in activity theory. It refers to collective problem-solving and attempting different systems of activity together [50]. This would require the need to engage with faculty from different specialties or organizations to ensure appropriate skill mix availability for the program. It is imperative to consider an ideal time for the targeted group. Evaluation involves measuring predefined indicators at all stages of implementation to demonstrate effectiveness. To achieve the best substantiation, the evaluation process should consider not only whether the program achieved its anticipated results but also any unintentional outcomes as well as intended and unintended developments. The process of evaluation is the final "gatekeeper," the findings from this step must be shared with all key stakeholders.

28.4.2.1 Simulation Project Planning

The backbone of project planning is the education strategy, with well-written measurable learning objectives that are essential to meet the needs and skill level of the learner. Enthusiastic trainers are a central part of any simulation program. A trainer with a strong foundation, in theory, will be able to understand the specifics of simulation. Most of the current simulation centers use modern technology, so a sound knowledge of new equipment and technology will aid in early adaptation to the program. In addition, to identify the perfect trainers, it is important for a simulation program to have an in-built trainer development plan [51]. With clear objectives, planning, and apprenticeship one can move from novice to master trainer. Usually, most trainers are exposed to core skills that are easily transferrable when they move from one module to another, and the most important one being the specific skillset that is unique to one simulation module.

Unfortunately, there is no globally accepted standard for trainers, but one should ensure that trainers are able to deliver consistent training for the learners, which in the long run helps to develop their own standards for a specific simulation program.

28.4.3 First (Pilot) Implementation Phase

The first implementation stage starts when the new program is first being put into practice. This is the most fragile stage in the implementation process, as a new program often nose-dives during this stage. New barriers and technical challenges are identified while the team is getting used to the “initial” program template, and this can contribute to failure. For the execution of the program first time, the implementation team should focus on (a) providing the required on-going assistance to staff responsible for program delivery, (b) measuring intervention fidelity, (c) quantifying outcomes, (d) sharing results with stakeholders, and (e) identifying new barriers.

The implementation team should consider whether they have enough necessary technical assistance to support the front-line program trainer to manage unexpected issues arising during the first delivery of the program. It is possible that further training, resources, or alterations may be necessary. Fidelity, in terms of implementation means, is the degree to which an intervention is implemented as recommended by the original protocol or program developers. An essential step in achieving high-fidelity is the adherence to the core program components (features without which the intervention will not have its intended effects). It is therefore important to contemplate intervention fidelity as well as implementation fidelity. The need to adjust programs to real-world settings while preserving program fidelity continues to be a persistent task of scaling up evidence-based interventions. Not gathering the information about what was done to achieve success would be unthinkable for a good implementation team; therefore, overlooking fidelity assessment may not allow identification of the strength of the intervention. That means a respectable outcome is not replicable. Attaining good outcomes once is commendable, but achieving good results repeatedly is educationally significant. The critical features of fidelity assessments include 3C’s—context, content, and competence [14, 52]. A frequent, appropriate, and actionable fidelity assessment should be considered to improve the program and outcomes. Furthermore, it is mandatory to consider a “live” evaluation of the program to recognize strengths and limitations as it unfolds, including the performance of individuals implementing the program. Evaluation with appropriate instruments is a systematic collection of evidence about the activities, characteristics, and results of the program to assess the program and implementation outcomes [53]. An effective process to communicate feedback to all stakeholders would help the implementation team to “iron-out” initial teething problems.

28.4.4 Full Implementation Phase

In this stage, the goal is to implement an “improved” program. The personal experience of the implementation team and information gathered following the “forensic analysis” of the pilot implementation process would encourage the quality implementation of the program. During full implementation, the program has largely been recalibrated to accommodate and support the new ways of work. The most important task for the implementation team is to learn from delivering the program and ascertain effective and unproductive aspects of the program in the local setting. The implementation team needs to focus on implementation outcomes such as acceptability, adoption, appropriateness, feasibility, cost, fidelity, penetration, and sustainability. One must use the existing taxonomy [54] for measuring

Table 28.2 Implementation outcomes (Adapted and modified from [54])

Implementation outcome	Definition	Implementation stage	Measurement method
Acceptability	Perception among stakeholders that the program is agreeable	Early for adoption Ongoing for penetration Late for sustainability	Feedback from trainees and trainers Administrative data
Adoption	Intention among stakeholders to introduce the program	Exploration stage	Needs assessment Interviews
Appropriateness	Perceived fit of the program for a given setting	Exploration stage	Needs analysis Interviews
Effectiveness	Impact of a program on important outcomes	Pilot and full implementation	Observations Feedback
Feasibility	Extent to which the program can be successfully used within a given setting	Exploration stage	Needs analysis Administrative data
Fidelity	Degree to which a program was implemented as intended by the program developers	Pilot and full implementation	Observation checklist Self-reporting
Implementation cost	Cost impact of an implementation	Exploration, pilot and full implementation stages	Administrative data
Penetration	Integration of a program within an organization	Full implementation stage	Course report Checklists
Sustainability	Extent to which the program is maintained over time	After full implementation	Review of reports Interviews Checklists

implementation outcomes (Table 28.2). To assess the success or failure of the implementation efforts, a logical method should be incorporated in the evaluation process for plausibility [55], areas of program improvement, options for further evaluation, and critique of the current data.

28.4.5 Innovation Phase

It is well recognized that a high-quality program will deteriorate over time without feedback on performance. The program may need adjustment due to the emergence of a new treatment/simulator or feedback from trainees. In this stage, the implementation team may decide to test innovations or improvements once the program has been implemented effectively. This may require discussion with the original program developer or expert, current facilitators, and trainers to ensure that the core elements of the program are preserved when modifications are considered. Some adjustments are necessary due to the suitability of the alteration for the local setting while maintaining sufficient fidelity. This should not be confused with program drift. Therefore, innovations should be scrutinized to prevent program drift [56].

28.4.6 Sustainability Phase

The sustainability phase of intervention has progressed in the past two decades. Implementation failure was considered if a program diverged from the originally specified steps from the original effective program in a particular setting even when the setting, population, or environments were quite different [57, 58].

What Keeps an Effective Program Sustained in the Long-Term?
The program can only deliver benefits to trainees if it is sustainable over time, and this should be considered at the program's conception, not as an after-thought. Sustainability describes the extent to which an evidence-based practice can continue to be delivered in the absence of external support or funding [59]. Understanding these factors can help stakeholders build capacity to sustain a program and position their efforts for long-lasting success. To assess sustainability, Schell et al. [60] suggest establishing a reliable financial base for the program, encouraging connections between the program and its stakeholders, program adaptation to ensure long-term effectiveness, maintaining relationships with internal and external (training committee, institutions, regulatory bodies) stakeholders, assessing the program to improve planning and results, sharing information with all stakeholders, to have internal or local support and resources required for effective management of the program and its activities, and to incorporate processes to guide the program's direction, methods, and goals.

In a simulation setting, according to Kirkpatrick and Kirkpatrick [61], evaluations of a training program are imperative to improve the training, augment the transfer of learning, and demonstrate the benefits of the training to the organization. The evaluation plan should be acknowledged in the needs assessment or analysis phase by recognizing what must be accomplished and determine the behaviors expected after the training. The Kirkpatrick Model [61] includes four levels of evaluation:

(a) Reaction—How satisfied is the learner with professional development?
(b) Learning—Is there a change in knowledge, skills, or attitude?
(c) Behavior—Has the learner applied what he or she has learned?
(d) Results—Is there a change in practice that improved student outcomes or organizational outcomes (e.g., patient safety or quality of care)?

Finally, constantly recruiting new stakeholders, simulation champions and trainers would energize the existing team and infuse new ideas. However, every program should consider their specific contexts and revamp the strategies that are most suited to their setting [62]. It is challenging to sustain a poor fit program or a program no longer suitable for the local setting in the manner it was initially introduced. It is, therefore, important to understand that sustainability is not a static process and that adapting a framework like the Dynamic Sustainability Framework (DSF) which incorporates the changing environment during program implementation can be useful. The DSF may allow the evolution of the program within a changing or different simulation setting [56]. In our experience with regard to simulation program funding, stakeholders, trainees, and the learning environment are particularly influential.

The Return on Investment (ROI) Institute recommends six categories of implementation goals (Table 28.3) when formulating an implementation plan for performance interventions. In simulation programs, apart from considering the financial return, it is important to assess the achievement of specified objectives [63, 64]. Focusing on the above objectives may help with the selection of models, define learning objectives, functional parameters, and assessment criteria.

Table 28.3 Categories of implementation objectives and questions related to categories (adapted and modified from [63, 64])

Objective	Comment
Reaction and planned action	This defines the level of reaction and satisfaction you want to achieve with both the target audience and major stakeholders. To consider the following questions • How important is user and stakeholder acceptance to you? • Aside from the simulated procedure, how difficult is it to operate the simulation? • Can the center provide independent documentation on acceptability? • Is the organization/center open to suggestions on content and new applications? • Will the simulation be considered relevant by your users and stakeholders (language, culture, local procedures, etc.)? • How difficult (time and money) is it to make the simulation relevant to your situation?
Learning	This defines specific changes in skills, knowledge, and attitudes in the target audience. Learning objectives are particularly applicable (but not exclusively) for training interventions • Is there any need for the program? • What are the performance objectives (task, conditions, and standards) the learners must master? • What specific aspects of the target procedure does the device simulate? • Does the simulator replicate the sensory inputs necessary to correctly perform the target procedure? If not, what is missing? • Has the simulation content been validated by recognized subject-matter experts? • Does the simulation provide performance feedback? • Has the simulation, when properly integrated with appropriate curricula, been proven to show transfer of learning when properly integrated and used with an approved curriculum? • Does the simulation have validated metrics? • Has the simulation been proven to distinguish between novice and expert performers? • Has the simulation been proven to have predictive validity? • Does the simulation have a user database that records performance? Can these data be exported? Is it secure? • How focused is the implementation team on your area of clinical education?

Table 28.3 (continued)

Objective	Comment
Application and implementation	This defines the level of success for the intervention, often in terms of utilization and sustainment over time. • Do you have implementation objectives or parameters (when, where, how many, how much)? • Can the center demonstrate quality control in the production process? • Does the simulation equipment meet local government standards? • Will the simulation work in your local conditions (electrical, humidity, temperature, space requirements)? • What is the failure rate/malfunction of the simulation equipment? • Is there any infrastructure to control and operate the simulation equipment? • What type of warranty and/or service support does the equipment supplier offer? Is it convenient and timely for your location(s)? Can the center provide proof of business stability and long-term sustainability? • Does the center offer suitable payment models? • What are the center's future plans for product additions and/or upgrades? • What are the licensing parameters and restrictions? Will you have a perpetual license to use the simulation or must the license be periodically renewed? • Can the simulator network with other simulators and learning management systems? • Is there any on-site or remote support from the equipment supplier?
Impact	Also referred to as the business impact, this generally comes from the gap analysis and defines the specific impact or change expected from the intervention • Are there specific gaps, in either individual or organizational performance, you need to address (complication rates, learner time to proficiency, team performance, etc.)? • Can the organization provide you with examples of how others have used the center's simulation equipment to bridge similar performance gaps? • Is there any plan to measure the impact?
Return on investment	This defines the actual cost versus benefits expected from the intervention. It is generally defined as ROI (%) = Net benefits/Net costs × 100 • Do you have specific, financial ROI targets? • Can the organization provide independently verified ROI case studies of situations similar to yours? • Does the organization have an independently verified ROI model?
Intangibles benefits	This defines those effects which are not addressed by the other objectives above. • Can the organization provide impartially verified examples of intangible benefits?

28.5 Implementation Ingredients for Simulation-Based Education

Proficient implementation of a program is as vital as various aspects of a good SBE program. An evidence-based simulation program coupled with effective implementation practices increases the likelihood of successful outcomes for learners in the medium and long run, following initial inception of the program. Importantly, evidence from implementation science suggests that even if the intervention or practice has been established as "successful" or "effective" by research, if it is not applied properly or without sufficient fidelity to the recognized model, it is likely to fail to achieve its intended outcomes.

What are the ingredients for the successful implementation of an evidenced SBE? A critical component for success in implementing change is that individuals within the team should feel committed and confident of their collective ability to change practice and be motivated to pursue this through their organization. Moreover, it has been suggested that a lack of structured preparation accounts for several good intervention efforts being unsuccessful [65]. Furthermore, successful SBE implementation with educationally significant outcomes requires effective innovations, efficient implementation, and facilitating frameworks. A simulation program incorporates learner (appropriate skills, delivery, faculty support, assessment, feedback, and evaluation), process (acceptance by the trainees, educators, policymakers, institutions, simulation delivery staff, and implementation team), and infrastructure (resources, learning environment).

In practice, we would argue that effective SBE implementation requires a process of "Bridging the Gap": Key stakeholders need to develop a shared understanding of the specific problems facing the population and possible gaps in the available services. The exploration part involves understanding the needs of the target group or population, incorporating EBP to address their needs, and ensuring the proven or promising intervention is the right fit between potential solutions and the local circumstance. It is important to consider feasibility, monitoring, and implementation quality as these aspects may influence design and ongoing EBP / program improvement. Elements included within the exploration phase:

- Quantify the gap between routine and potential care with proven or promising interventions
- Barrier analysis to understand resistance for a change to occur
- Describe what stakeholders will do to implement a change
- Enable successful adaptation of the intervention
- Assess implementation and outcomes longitudinally
- Understand the sustainability of change

28.6 Application of Implementation Science Principles to Simulation-Based Education: Development and Scaled Implementation of the Urology Simulation Boot Camp

In the United Kingdom, the General Medical Council (GMC) supports the "provision of simulation-based learning opportunities to trainees during their training program." Also, the traditionally known Halstadian concept of "See One, Do One and Teach One" has changed over the years, and the current model supports simulation-based learning prior to entering clinical settings. The Urology Simulation Boot Camp (USBC) course has been incorporated in the UK urology training program. The course was piloted in 2015 [66] and was recommended to all new urology residents in the UK from 2018. By following the implementation science principles, we have managed to improve delivery, sustainability, and innovations. Since its inception, the course has maintained a few key principles:

(a) *"1 trainee—1 trainer—1 model"* template
(b) Maximum hands-on experience
(c) Adherence and changing with National training curriculum
(d) Equal importance to technical and non-technical skills
(e) Course delivery at the start of the training program.

28.6.1 Exploration Phase

The fragmented and variable skills training during core surgical training were the catalyst for the new idea of the structured USBC at the start of urology training. One of the course organizers (CSB) had good experience of running procedure-specific courses, a 5-day multi-specialty course on the management of surgical emergencies for surgical residents in Africa and a 2-day multi-specialty surgical course for foundation trainees in the UK. In addition, the boot camp approach was introduced in other surgical specialties like cardiac and vascular surgery [67, 68]. The urology curriculum was explored to assess the current needs of training and this was used to prepare a draft model for the Boot Camp. The curriculum highlighted developing competency in common urological emergency surgical skills, basic endoscopic urological procedures, and non-technical skills. Following a needs assessment, a steering group was created and all stakeholders were involved, including the Chair of the Training Committee.

28.6.1.1 The Needs Assessment

Though there were urology courses during the specialty training in urology, there were a lack of structured courses at the start of the training program. Furthermore, as a team, we had experience in conducting "Bridging the Gap" courses at transition levels for foundation and core surgical training. Therefore, a course for urology trainees while transitioning from core surgical training to specialty urology training appeared necessary.

Before implementing the USBC in the UK [66], various questions and aspects were considered: What type of SBE was available for a new resident in urology? What other surgical boot camps are being delivered? Is there any content, resources, or facilities that can be used from the existing model? The needs assessment survey of newly appointed urology trainees received over 90% support for a 3-day hands-on simulation training course at the start of the registrar training covering common urological procedures, i.e. transurethral prostate resection (90%), cystoscopy and ureteroscopy (90%), suprapubic catheter (80%), and scrotal procedures (80%).

28.6.1.2 Setting Up of Steering Group with Stakeholders

A steering group consisting of senior urology consultants, a training committee chair, educators, and administrative staff was set up to oversee the whole process. A detailed discussion with relevant stakeholders was conducted to outline the boot camp idea and further planning and design of the USBC. In the initial needs assessment survey, a 3-day course was preferred by trainees', but the Steering group recommended a 5-day program to provide a comprehensive course with technical, non-technical, and "soft" skills, including assessment. Considering the mammoth task of setting up a new program, a proposal was drafted with a timeline to deliver the pilot course in 12 months (Fig. 28.2). The team worked on several components of the proposal in-parallel for safe implementation on the USBC. As a part of the long-term planning of SBE, the steering committee also suggested a boot camp timetable for the Specialty training in urology that consisted of introductory, intermediate, and advanced boot camps at ST3, ST4/5, and ST6/7 levels, respectively (Fig. 28.3).

28.6.2 Preparation Phase

Our initial goal was to increase the accessibility of urological skills training to newly appointed trainees. The literature search was performed to gather available evidence across the world of similar courses. A neurosurgery boot camp [69] and a few others were used as a guide, and a draft plan was prepared for our first boot camp. After several meetings and discussions between the Steering group and key members, the draft plan was revised to formulate an eight-module USBC. At the

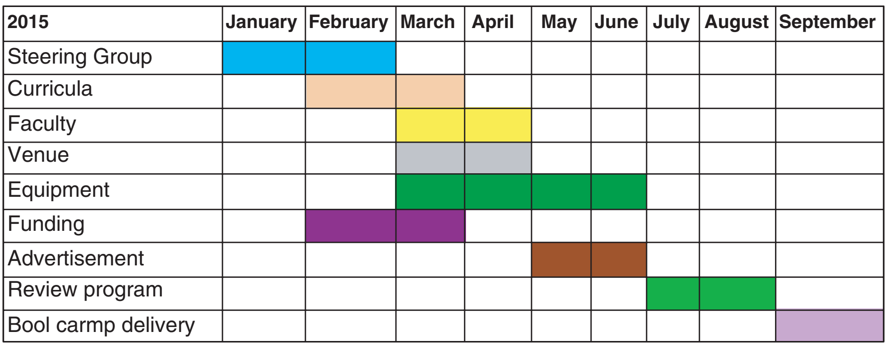

Fig. 28.2 Pilot Urology Boot Camp proposal plan

ST3 Introductory Boot Camp	Annual Boot Camp	ST4/5 Intermediate Boot Camp	Annual Boot Camp	ST6/7 Advanced Boot Camp
Central	**Local**	**Central**	**Local**	**Central**
Basic procedures on synthetic or virtual reality simulators as per ST3 curriculum		Cadaveric Human factors as per ST4/5 curriculum		Cadaveric Sub-specialty specific as per ST6/7 curriculum

Fig. 28.3 Graded Urology Boot Camp proposal (*ST* Specialty Trainee)

same time, trainees' opinions were gathered to assess the needs, and information was shared with other stakeholders, such as the training committee and deanery, to explore the practicality of the USBC. A major hurdle was the funding and the faculty selection. We approached our deanery, industry, and some charities with a copy of our proposal. A well-structured and detailed plan of providing an "all-inclusive" learning experience and our track record, worked in our favor to secure the funding.

The next step was the careful planning of each module and the identification of simulation models that were to be used for each module. Separate discussions were arranged with module leads for the safe planning of module content, co-faculty, program, simulation models, and finally the delivery. To appraise the training, assessments were planned for each module, in addition to evaluation and feedback on each module by trainees, and a course evaluation by trainees and faculty were also considered. We adopted an ABCDE approach to develop the boot camp. We feel that **A**ssessment, Faculty (**B**uddy), **C**ontent, **D**elivery, and Learning **E**nvironment are indispensable components of a successful simulation program (Fig. 28.4). The course contents are like the skeleton of a program and well-thought-out content would keep the program "standing." The faculty members are like the heart; the multimodality delivery methods may represent the nervous system; the assessment methods symbolisze the lungs; and finally, the learning environment epitomizes the skin of a program.

To augment the learning experience of the non-technical skills, we considered multi-specialty faculty members and therefore included anesthetists, acute care physicians, and nurse consultants. The curriculum for the new urology residents was included in the course covering technical and non-technical skills. For other "soft skills," short evening lectures and course dinner were considered. We ensured that a trainee should get maximum practical experience, like "real-life" operating theater proficiency. We, therefore, planned to have one trainer for each trainee. We strongly believe that as effective training can be delivered to only one trainee in a theater setting during live operating, then the same applies to the simulation setting. Practically, it is difficult in the simulation setting due to the number of trainers

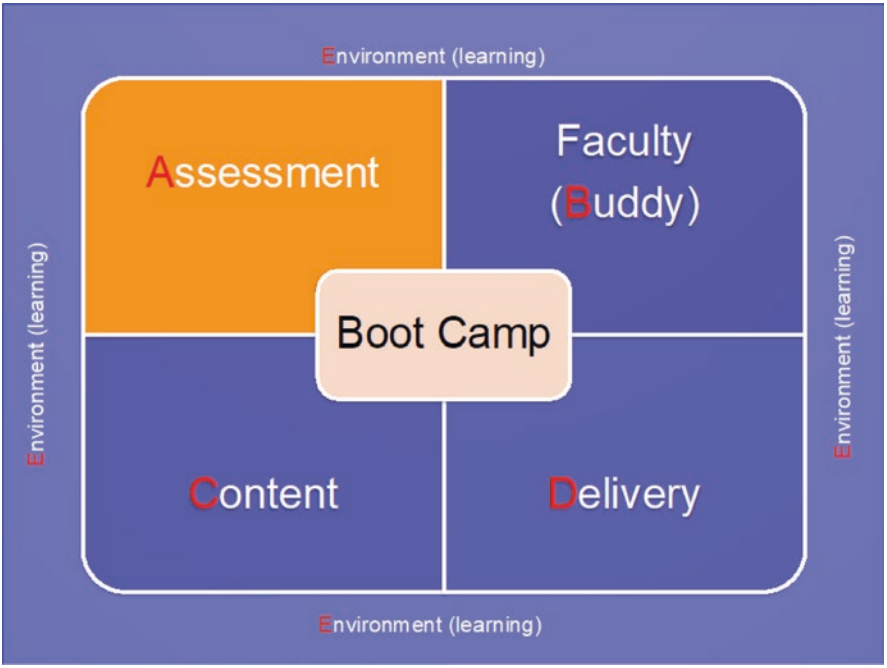

Fig. 28.4 The ABCDE approach for a boot camp

required to deliver the program; however, we are convinced that by having more than one trainee for technical skills training, you may deliver suboptimal training to everyone. A variety of models were included, and a select number of companies were approached for funding and equipment support. The pilot course was aimed at a mixed group of trainees; therefore, data on their previous urological operative experience was gathered. This then allowed us to group trainees with the same level of experience into one group. Not paying attention to trainees' needs and experience in a group can compromise the training of each trainee in the group and would also require the trainer to readjust the contents to accommodate everybody's needs. One advantage of our 1:1:1 training template is that the majority of the time, the training can be tailored to the needs of the individual trainee. A number of evaluation and assessment forms were drafted [70].

Urology simulation Boot Camp (USBC) involves eight different modules consistent with different simulation methodologies, complexity, and the use of several complex pieces of equipment, so the trainers need to understand the intricacies of this process, including the depth and breadth of this process. USBC trainers are exposed to Non-Technical Skills for Surgeons (NOTSS) training in addition to specific in-house training for each module [66]. A simulation program with multiple modules may require a good number of trainers. For the pilot USBC, we had to identify over 30 trainers each day for the efficient delivery of four modules as a 1:1 training ratio. The current USBC requires >50 trainers every day to deliver 8 modules. This allowed the lead to form an enthusiastic trainer group and ensure buy-in from like-minded colleagues. We avoided “parachuting” a trainer into a group to maintain the balance.

28.6.3 Pilot Implementation

In September 2015, a pilot USBC was conducted for 16 urology and core surgical trainees. The initial pilot consisted of two blocks of four modules of 4-hour each, run over two days that were attended by a group of four trainees (Fig. 28.5a). Each

Friday Saturday	Circumcision Scrotal examination Testicular fixation Hydrocele SPC	Bowel anastomosis Stoma formation Bladder and ureter repair	Basic lap skills Access Lap trainer box E-BLUS exercises LAP Mentor exercises	URS TURP TUBT GLL
Sunday Monday	Scenario	Botox TOT/TVT Urodynamics	Cystoscopy stent Bladder wash out Instruments Energy—Laser & Harmonic	URSTURP/TURBT/GLL
Tuesday	Assessment			a

2016	Scrotal examination Testicular fixation Hydrocele Communication Step up from CT to ST Leadership, Priapism Penile fracture		Bowel anastomosis Stoma formation		Basic lap skills Access Lap trainer box E-BLUS exercises LAP Mentor exercises		TURP TUBT Bladder wash out Instruments-resectoscope/Urethrotome	
	AM 8:30 to 12:30	PM 13:00 to 17:30	AM 8:30 to 12:30	PM 13:00 to 17:00	AM 8:30 to 12:30	PM 13:00 to 17:00	AM 8:30 to 12:30	PM 13:00 to 17:00
Thursday 15th September	A	B	C	D	E	F	G	H
Friday 16th September	B	C	D	E	F	G	H	A
Saturday 17th September	C	D	E	F	G	H	A	B
Sunday 18th September	D	E	F	G	H	A	B	C
Monday 19th September	Assessment (8:30) to 11:30)				Lectures (11:45 to 14:45)			
	Scenario (general)		Botox, urodynamic TPOT?TVT		Ward based scenarios		URS/accessories Cystoscopy stent Instruments-cystoscopy	
	AM	PM	AM	PM	AM	PM	AM	PM
Thursday 15th September	E	F	G	H	A	B	C	D
Friday 16th September	F	G	H	A	B	C	D	E
Saturday 17th September	C	H	A	B	C	D	E	F
Sunday 18th September	H	A	B	C	D	E	F	G
Monday 19th September	Lectures (8:00 to 10:30) Human factors Laser safety, Ionising radiation, Uroradiology				Assessment (11:00 to 13: 30)			b

Fig. 28.5 (**a**) The pilot course contents in 2015 and (**b**) full implementation of a modified program in 2016 (*SPC* Suprapubic catheter; *TOT/TVT* Trans obturator/vaginal tape; *E-BLUS* European Basic Laparoscopic Urological Skills; *URS* Ureteroscopy; *TURP* Transurethral resection of the prostate; *TURBT* Transurethral resection of the bladder tumor; *GLL* Greenlight laser prostatectomy)

module had an initial briefing followed by hands-on training by experienced consultants. The course had a mixture of intensive 30-hour of technical training and 4-hour of non-technical skills training over five days. In-line with the curriculum outlined by the SAC, the course aimed to provide hands-on experience in common urological procedures and enhance professional development. Each trainee had an opportunity to practice at least 5 procedures each in transurethral resection of the prostate (TURP), transurethral resection of bladder tumor (TURBT), ureteroscopy rigid/flexible (URS), and basic laparoscopic skills. The assessment of trainees was performed on the last day. The experience from the pilot course gave us the following important information.

1. The majority of course contents, models, and assessment methods worked well.
2. The administrative and technical staff functioned as a team.
3. The support and funding from the industry partners paid dividends, and they also found the whole experience useful with the assurance of regular support.
4. Feedback from the trainees highlighted strengths and limitations (Table 28.4).

We presented our full report (119 pages) with outcomes to the training committee, and the findings were very well received.

28.6.4 Full Implementation Phase

Riding high in confidence due to the success of the pilot course, we incorporated comments from the feedback and recalibrated the program. It was decided to deliver all 8 modules every day for 4 days with 32 trainees (4 in a group) and increase non-technical skills to 2 modules (Fig. 28.5b).

Table 28.4 Feedback from the pilot course 2015

What was good?	What can be improved?
• Fantastic course. Worth every penny and would recommend it to any new ST3. ***Fully support it being mandatory***. Very well run. • ***Faculty excellent,*** catering excellent, organization extremely well done, simulators very realistic, easily best course I've been a part of and excellent value for money. • Really good course at my stage of training. I feel a lot more confident at tackling basic urological procedures now under the supervision of my consultant. • The ***human factors scenarios*** were of particular use, as they provided communication tips that can be adopted into practice straight away. The best course I have ever attended. Thank you! • I think this was the ***best surgical skills*** and medical course that I have ever attended, even ***better than*** the RCSEng Operative Modules in Urology.	• ***Less pre-course reading material to enable*** candidates to actually read it. The IRMER reading was too much and not possible to get through as was the laparoscopic module. • A laser course that would actually give us certification to use the laser. Not sure if the training was sufficient to be safe laser uses. • Give a rough indication as to the ***time the pre course work*** is expected to take so we can easily plan our time ahead of the course. • A ***healthier lunch*** selection would be great! • ***Monday-Friday instead of over the weekend.*** • Module-specific learning objectives for every module would be useful. • Assessment day was not that useful, only required half a day not a full day.

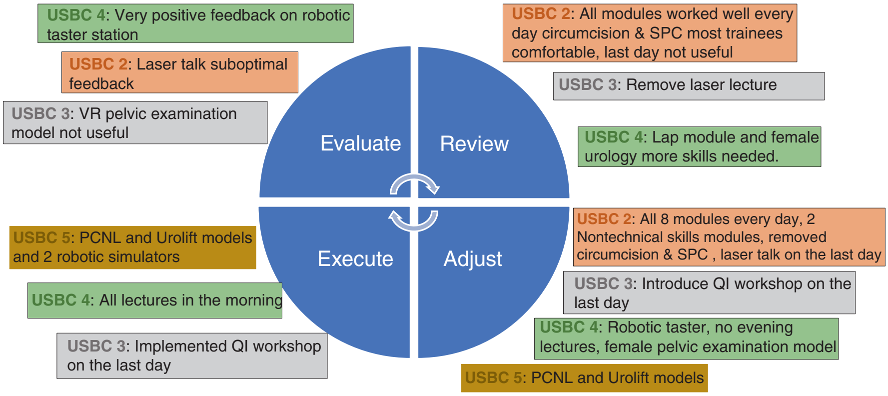

Fig. 28.6 Review, Adjust, Execute, and Evaluate (RAEE) cycle. *PCNL* percutaneous nephrolithotomy; *QI* quality improvement; *SPC* suprapubic catheter; *USBC* Urology Simulation Boot Camp (course number); *VR* virtual reality

The circumcision and suprapubic catheter insertion were removed as most trainees were competent. To maintain a high-quality learning experience, we practiced Review, Adjust, Execute, and Evaluate (RAEE) cycle (Fig. 28.6) with regular readjustment to the program [70, 71]. It was noted that during evening lectures, trainees appeared tired; therefore, lectures were moved to the morning, followed by hands-on training, without compromising on the training time. The reason behind it was that if trainees are practicing hands-on training, they may enjoy it due to active participation even at the end of the session. The change worked well. There is a persistent analysis of the assessment and evaluation forms. Following a review, the Non-Technical Skills for Surgeons (NOTSS) form was incorporated into the non-technical skills modules. An interactive workshop on Quality Improvement has been fully embedded in the course since 2017 [72]. A checklist to monitor the steps in the implementation process was very helpful (Table 28.5).

28.6.5 Innovation and Sustainability Stages

A regular critical evaluation of the feedback from trainees and trainers with the core group and the dissemination of the report were key components to keeping the program sustainable (Fig. 28.6). We regularly shared the full report with sponsors and published our results in peer-reviewed journals [70, 73, 74]. We always request our hospital's Chief Executive, Chief Medical Officer, Medical Director, Dean, Training Committee Chair, British Association of Urological Surgeons President, Head of School of Surgery, and Senior Managers from the industry to visit the course. It helps in two ways, one it encourages trainers, and they feel appreciated; second, sponsors can see the immediate impact of their support. By adopting this approach, we have managed to secure funding for the course every year. We have developed four "in-house" models for the course [75–78]. It is the responsibility of the course

Table 28.5 Flowchart for the Urology Simulation Boot Camp (highlight with **green** once completed)

Month	Job	Responsible person			
		Course Directors	Module Lead	Administrative staff	Technical staff
October	Fix the date for next year boot camp and ensure venue booking is secured	+		+	
	During the course—ongoing support to the faculty	+	+	+	+
	Collect evaluation forms	+	+	+	
	Post course Thanks email to trainers, trainees, sponsors	+		+	
	Thanks email to module leads	+			
	Inform trainers about the next year's course	+	+		
	Issue certificate to trainers			+	
	Confirm next year's dates to morning lecture speakers	+		+	
November	Prepare report	+	+		
	Issue Trainees' Summary Sheet	+			
	Prepare and review account	+		+	
	Disseminate report	+			
	Request funding for the next course from training committee/industry	+		+	
December	Reflection by course directors and module leads	+	+		
January	Teleconference with module leads	+	+	+	
	Any adjustment needed?	+	+	+	+
	Review equipment list	+	+	+	
	Confirm equipment with sponsors			+	
	Contact faculty			+	
	Apply for CPD and add to the BAUS Event calendar			+	
March	Core group meeting finalize the program and flyer, course fee	+		+	
	Consider inviting important stakeholders	+		+	
	Approach a trainee for data collection	+			

Table 28.5 (continued)

Month	Job	Responsible person			
		Course Directors	Module Lead	Administrative staff	Technical staff
April	Disseminate flyers at the National Selection, online platform			+	
May	Contact module leads and assess needs			+	
	Open registration for delegates				
	Review course contents and online platform	+	+	+	+
June	Assess faculty confirmation	+	+	+	
July	Accommodation and dinner booking			+	
	Course lunch			+	
August	Recheck faculty and try to fill up gaps	+	+	+	
	Contact morning lecture speakers	+		+	
	Recheck consumables	+	+	+	+
	Approach junior doctors for module 7	+			
	Contact urology ward for staff nurses			+	
	Contact Storz for delegates bags			+	
	Confirm actors			+	
September	Prepare the course program (timetable)	+		+	
	Prepare assessment day timetable	+		+	
	Faculty allocation	+	+	+	
	Review assessment and evaluation forms	+		+	
	Prepare signs for the course			+	
	Book IT support and porter			+	
	Book lunch			+	
	Check accommodation for faculty			+	
	Contact sponsors and reps with delivery details for the venue and contact name			+	+

Fig. 28.7 Evolution of the Urology Simulation Boot Camp (*recommended to all new urology trainees)

directors to ensure that the trainers are well supported. We pride ourselves on developing a good number of "die-hard" boot camp trainers carrying "boot camp DNA." This is evident by the fact that the core group comes back every year to deliver the course and new trainers are joining the course. Due to the intense nature of the course, we always plan to have some extra faculty members to provide well-deserved rest to faculty members in between. In addition, they may be able to fill in any last-minute faculty dropouts. To support the faculty, we have delivered 2 courses on NOTSS. We hope that it would provide standardized feedback to all learners. We aim to do this annually. We have also managed to modify and adapt the course for the first year urology residents in Europe [79] due to favorable implementation outcomes and course feedback (Fig. 28.7).

28.7 Summary

Overall, implementing an effective simulation program is an enormous task, and transferring the program from one setting to different settings is challenging. The principles of implementation science should be followed to optimize the benefits of a simulation program whether it is a local or national execution. No two implementation events are the same due to all kinds of internal and external factors. Undoubtedly, implementation science can provide direction, early recognition of barriers, minimize resource wastage, increase acceptance, and improve outcomes for future innovations. For quality implementation, adherence to the linked steps is paramount.

Key Points

- To transfer evidence-based interventions into practice, several strategies may be desirable.
- What works in one context of care may or may not work in another setting, thereby implying that context variables matter in implementation.
- The implementation process can be viewed scientifically in terms of a sequential series of interconnected steps that should be successfully adopted to augment the prospect of quality implementation.
- Urology Simulation Boot Camp program success highlights the significance of incorporating implementation strategies in developing complex SBE interventions.

Conflicts of Interest

CSB and VH are the Directors of the Urology Simulation Boot Camp.

NS is the director of London Safety and Training Solutions Ltd., which offers training in patient safety, implementation solutions, and human factors to healthcare organizations. The other authors have no conflicts of interest to declare.

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Appendix: Resources

Model	Link/Reference	Measure Construct
"4E" Framework for Knowledge Dissemination and Utilization	https://cpr.bu.edu/develop/4e-framework/	Adopter/implementer/decision maker characteristics, Dissemination, Knowledge and knowledge synthesis, Translation, Strategies

Model	Link/Reference	Measure Construct
Active Implementation Framework	https://nirn.fpg.unc.edu/ai-hub	Adoption, Awareness, Barriers and facilitators, Communication channels, Evaluation, Fidelity, Implementation, Innovation characteristics, Pre-implementation, Maintenance and sustainability, Process, Readiness, Strategies
Consolidated Framework for Implementation Research (CFIR)	https://cfirguide.org/	Adaptation and evolution, Adopter/implementer/decision maker characteristics, Goals, Champion/field agent, Communication, Compatibility, Complexity, Context—Outer setting, Cost, Engagement, Evaluation, Implementation, Innovation characteristics, Trialability, Knowledge and knowledge synthesis, Patient/target audience characteristics and needs, Process, Readiness, Relative advantage
Davis' Pathman-PRECEED Model	Davis D, Evans M, Jadad A, et al. The case for knowledge translation: shortening the journey from evidence to effect. BMJ 2003;327(7405):33–5	Acceptability/feasibility, Adoption, Awareness, Barriers and facilitators, Innovation characteristics, Pre-implementation, Outcomes—Health/QOL/Satisfaction/Clinical, Patient/target audience characteristics and needs, Strategies
Dynamic Sustainability Framework	Chambers DA, Glasgow RE, Stange KC. The dynamic sustainability framework: addressing the paradox of sustainment amid ongoing change. Implementation Sci 2013; **8,** 117.	Adaptation and evolution, Context—Inner setting, Context—Outer setting, Evaluation, Outcomes—Quality Improvement/Practice or Policy change, Stakeholders
Exploration, Preparation, Implementation, Sustainment (EPIS) model	https://episframework.com/	Acceptability/feasibility, Adopter/implementer/decision maker characteristics, Adoption, Awareness, Development of an intervention, Barriers and facilitators, Champion/field agent, Communication channels, Context—Inner setting and outer setting, Fidelity, Fit, Implementation, Knowledge and knowledge synthesis, Pre-implementation, Maintenance and sustainability, Strategies
Generic implementation framework	Moullin JC, Sabater-Hernández D, Fernandez-Llimos F et al. A systematic review of implementation frameworks of innovations in healthcare and resulting generic implementation framework. Health Res Policy Sys 2015; 13, 16.	Barriers and facilitators, Context, Evaluation, Implementation, Innovation characteristics, Pre-implementation, Strategies

Model	Link/Reference	Measure Construct
Health Promotion Technology Transfer Process	Orlandi MA. Health promotion technology transfer: organizational perspectives. Can J Public Health. 1996 ;87 Suppl 2:S28-33. PMID: 9002340.	Adaptation and evolution, Development of an intervention, Dissemination, Evaluation, Identification, Outcomes—Implementation
Implementation Effectiveness Model	Klein KJ, Sorra JS. The Challenge of Innovation Implementation. Academy of Management Review, 1996;21: 1055-1080.	Adopter/implementer/decision maker characteristics, Adoption, Barriers and facilitators, Communication channels, Context—Inner setting, Fidelity, Fit, Implementation, Innovation characteristics, Outcomes—Implementation, Readiness, Strategies
Normalization Process Theory	http://www.normalizationprocess.org/	Evaluation
Practical, Robust Implementation and Sustainability Model (PRISM)	http://www.re-aim.org/	Acceptability/feasibility, Adaptation and evolution, Adopter/implementer/decision maker characteristics, Barriers and, facilitators, Communication, Complexity, Context—Inner setting and outer setting, Cost, Innovation characteristics, Trialability, Maintenance and sustainability, Outcomes—Health/QOL/Satisfaction/Clinical, Outcomes—Quality Improvement/Practice or Policy change, Patient/target audience characteristics and needs, Readiness, Stakeholders
Precede-Proceed Model	*Green LW, Kreuter MW. Health Program Planning:* An *Educational and Ecological Approach. 4th Edition. New York: McGraw-Hill, 2005.*	Barriers and facilitators, Communication channels, Innovation characteristics, Pre-implementation, Outcomes—Health/QOL/Satisfaction/Clinical
Promoting Action on Research Implementation in Health Services (PARIHS)	Kitson A, Harvey G, McCormack B. Enabling the implementation of evidence-based practice: a conceptual framework. Qual Health Care. 1998 Sep;7(3):149-58.	Adoption, Context—Inner setting, Implementation, Innovation characteristics, Readiness
Pronovost's 4E's Process Theory	Pronovost PJ, Berenholtz SM, Needham DM. Translating evidence into practice: a model for large scale knowledge translation. *BMJ* 2008 Oct 6; 337:963-965.	Barriers and facilitators, Engagement, Evaluation, Implementation, Innovation characteristics, Reach
RE-AIM 1.0 Framework	http://www.re-aim.org/	Adoption, Implementation, Innovation characteristics, Maintenance and sustainability, Reach

Model	Link/Reference	Measure Construct
RE-AIM 2.0/ Contextually Expanded RE-AIM	http://www.re-aim.org/	Adaptation and evolution, Adoption, Context—Inner setting and outer setting, Cost, Fit, Implementation, Innovation characteristics, Maintenance and sustainability, Outcomes—Implementation, Reach Strategies

Modified and adapted from https://dissemination-implementation.org/viewAll_di.asp

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