Simulation in Surgery

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Introduction

Medical training has always relied upon the patient serving as the instruments of medical education. Halsted's apprenticeship model was centered around the mantra: "See one, do one, teach one" [1]. Under this model, trainees practice their craft on patients and are required to learn quickly, often through their mistakes. Although this objective was intended to function with proper oversight and controls, this method of learning has long been the subject of debate about the safety and ethicality of training on patients [2]. As such, finding ways to bypass or accelerate the early learning curve has become paramount. One way physicians are amending their training while keeping patient safety paramount is through simulation. This is a relatively new and emerging field with the aim to allow trainees to practice techniques and procedures in a controlled environment that does not jeopardize patient health [3].

Urology is a specialty that has been pushing the boundaries of new technologies since the early 1900s. Simulation is particularly enticing in urology, because with new technology and techniques comes significant learning curves. Even urologists who have been in practice for many years are finding that they have to learn new procedures outside of their traditional training. This is especially challenging to attending physicians, as they are responsible for helping teach residents procedures that they are also relatively inexperienced with.

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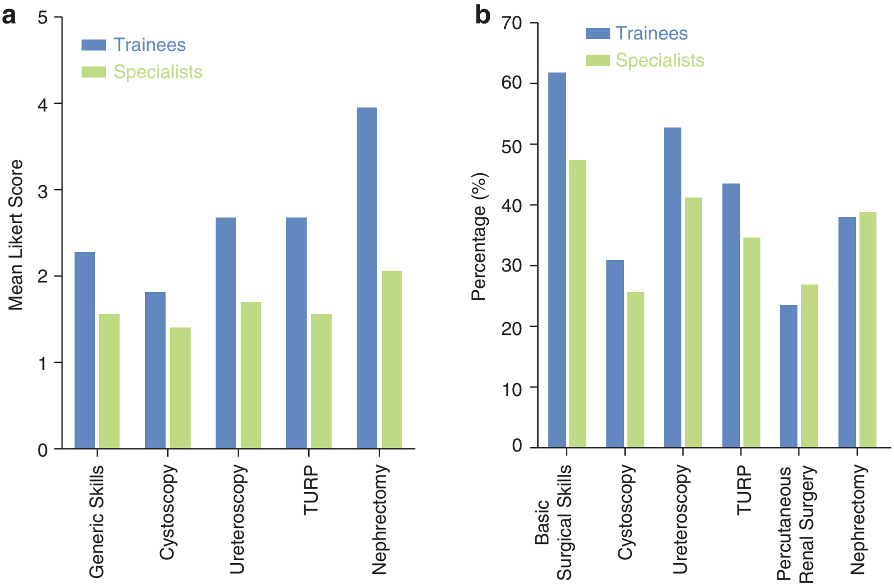

Fig. 24.1 Results of survey of 263 urological trainees and specialists comparing perception of need for additional training and whether or not simulation had been used for training [173]. (**a**) Is additional training required to develop technical skills? Likert scale: (1 = strongly disagree – 5 = strongly agree) Key: *TURP* transurethral resection of the prostate. (**b**) Percentage of trainees and specialists who had simulation experience in technical skills training. Likert scale: (1 = strongly disagree – 5 = strongly agree) Key: *TURP* transurethral resection of the prostate

The Accreditation Council for Graduate Medical Education (ACGME), the governing body of American medical residencies, is tasked with assuring that residents are properly trained before independent practice. In their most recent release of requirements for urology residencies, the ACGME states that residencies are responsible for "developing the skills, knowledge, and attitudes leading to proficiency in all the domains of clinical competency requires the resident physician to assume personal responsibility for the care of individual patients." The way in which residencies need to reach this goal is never explicitly stated. Despite no requirements from the ACGME at the time of this writing, residencies are increasingly using simulation and skills laboratories to help residents master a number of surgical skills (Fig. 24.1). In the following chapter, the currently available simulation options in urology will be discussed including open surgery, laparoscopy, robotics, and endoscopy.

Open Surgery

Despite more minimally invasive surgical approaches at the urologists disposal today, open surgery remains the backbone of urological surgery. Because of the growing number of surgeries being done in a minimally invasive manner, trainees have had less exposure to open surgery. Therefore, simulation in open surgery is one way of gaining open experience without putting patients at risk. Currently available simulators for open surgery are comprised of bench models, cadavers, and animal models.

Human cadavers likely represent the best option for open surgery simulation, but cadavers are expensive and often not readily available. In a large study comprised of 81 urology residents and 27 urology faculty members, Ahmed et al. recently put forth a simulation program in which participants performed a number of procedures on fresh-frozen cadavers [4]. These procedures included circumcision, vasectomy, orchiopexy, hydrocele repair, radical orchiectomy, open cystotomy, management of bladder perforation, transureteroureterostomy, Boari flap, psoas hitch, open surgical packing of the pelvis, and nephrectomy [4, 5]. Questionnaires of the participants indicated that the cadaveric simulations had face validity (mean score 3/5) and all procedures scored ≥3 out of 5 in terms of usefulness for learning anatomy and improving surgical skills (content validity). Interestingly, participants rated human cadaveric simulation to be the best form of training, followed by live animal simulation, animal tissue models, bench models, and virtual reality.

Because cadaver simulations are simply "surgeries" performed the same way as they would be in living patients, these will not be discussed individually. Described below are the few currently validated non-cadaveric models of open surgery.

Bladder

Suprapubic Tube Placement

Suprapubic tube (SPT) placement is a rather common procedure performed by urologists, but trainees often have to "learn on their feet" as this is a procedure often done alone and sporadically in an emergent setting. Because of this, trainees often have difficulty acquiring the skill and confidence to perform the procedure and many times elect to attempt difficult urethral catheter placement, which may put a patient at increased harm. To bolster the skills necessary for SPT placement, there are currently three validated bench models that can be used by trainees for procedural simulation.

The first SPT model called the "UroEmerge™ Suprapubic Catheter Model" was described by Shergill et al. in 2008 [6]. The authors created the model by injecting a 3 liter bag of irrigation fluid with 10 cc of povidone-iodine, giving the fluid a urine color, and tying the bag with two tourniquets to simulate a full bladder (Fig. 24.2). This "bladder" was then placed within a plastic trainer housing and covered with a commercially available abdominal open and closure pad which simulates abdominal skin, subcutaneous fat, and rectus sheath (Limbs & Things, UK) (Fig. 24.3).

Fig. 24.2 Bristol TURP simulator [110]

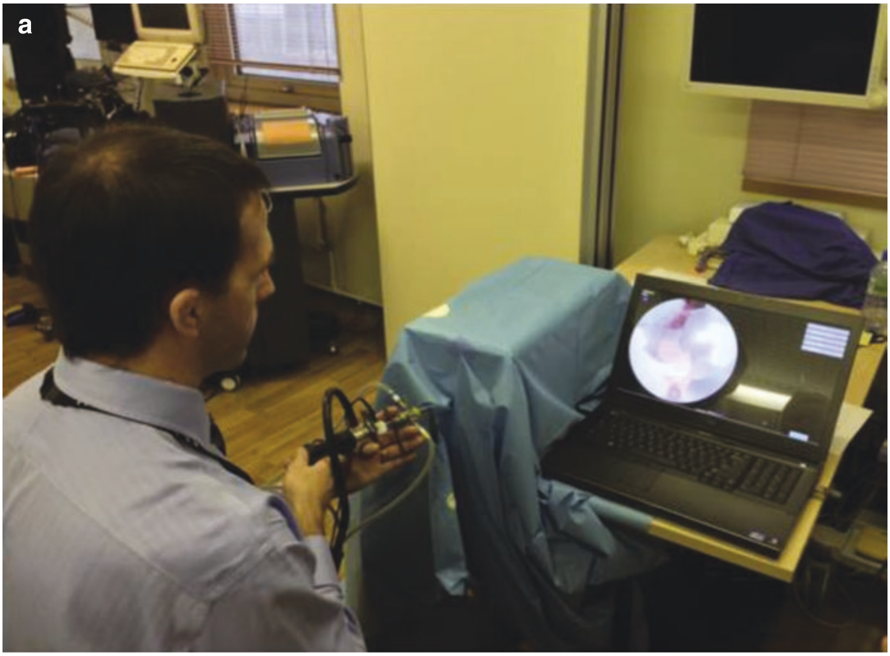

Fig. 24.3 (**a**) The UroSim simulator with resectoscope and display in use, (**b**) view of simulated prostatic anatomy, (**c**) mid-procedure view notable for circular fibers seen at bladder neck [128]

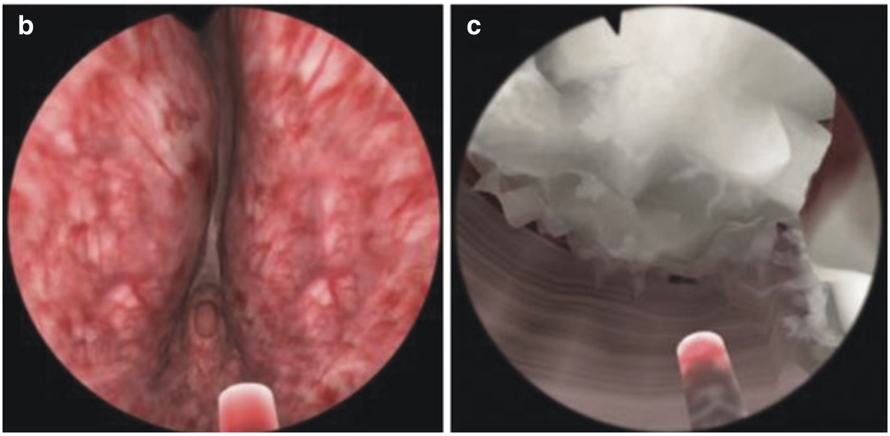

Fig. 24.3 (continued)

Shergill et al. had 36 participants use the model for SPT insertion and scored their ability using a 0–5 visual analog scale. The authors found that before training, the participants had an average score of 3.14 for ability to do SPT placement, which increased to 4.48 after the course. This suggests that this model may be a viable and easy method to help junior residents learn this procedure.

A second model was published by Hossack et al. in 2013, which, again, is relatively simple in nature [7]. The model is made by filling a standard party balloon with tap water and affixing it with tape. The authors recommended “Mefix” tape (Molnlycke Health Care, Sweden) because it kept adherence to the balloon even when wet, prevented the balloon from popping, and provided realistic resistance to trocar placement. The balloon was then placed within a plastic container with a hole cut in the lid. On top of the balloon, a standard household sponge was placed (representing perivesical fat), on top of which a three-layer square of Transpore (3 M) tape was placed (rectus sheath), and finally covered with another sponge (abdominal wall fat). In their study with 30 surgical resident participants, the authors found that 96% felt the model accurately represented a bladder and 84% felt much more confident in performing SPT insertion [7].

Singal et al. described the most recently published model in 2015 [8]. The model was created by first making a bony pelvis from urethane foam and stabilized with resin glue. Plastic parts simulating the anterior superior iliac spine and pubic symphysis were embedded within the foam to provide palpable bony landmarks. The bladder was constructed from silicone rubber with attached IV tubing and Luer Lock syringe for instillation of fluid. This was then filled and placed within the bony pelvis and covered with multiple skin and fat layers (made of silicone rubber and gel wax). The model was studied with 25 rural general surgeons under the supervision of urologists. The surgeons scored the model well in terms of value as a training or testing model (4.1/5) and overall realism (3.9/5) [8].

Vas Deferens

Vasovasostomy

Vasovasostomy (VV), or vasectomy reversal, is an option for men who have undergone sterilization vasectomy but wish to regain their fertility. Vasovasostomy is a very technically demanding procedure because the structures are small and suturing is usually performed under a microscope. Sutures are often quite small (9-0, 10-0, and/or 11-0).

In the only validated study of VV simulation, Grober et al. randomly assigned junior surgery residents to learn VV via a high-fidelity model (live rat vas deferens), a low-fidelity model (silicone tubing), or didactic training alone (control group) [9]. After training in their given randomization group, participants returned 4 months later for retention testing on the two models. The authors found that those who were randomized to either bench model performed significantly better than the didactic control group as evidenced by higher retention test checklist scores (25.5 vs 18.6, $p < 0.001$), higher global rating scores (27.0 vs 16.4, $p < 0.001$), and patency rates (69% vs 20%, $p = 0.05$) [9]. The authors did not distinguish scoring between the low- and high-fidelity model trained groups.

Laparoscopy

Laparoscopy is a growing field of urology, as urologists continue to push the boundaries of what is possible within the realm of laparoscopic surgery. Laparoscopic surgery was first introduced in the 1970s by gynecologists attempting laparoscopy for oophorectomies and myomectomies, but it did not become mainstream until expansion into general surgery with two of the most commonly performed surgeries today—laparoscopic cholecystectomy and appendectomy [10]. Since the early 1990s, minimally invasive surgery (MIS) has grown tremendously in the field of urology, with an increasing number of indications for MIS. Although, with its advances, laparoscopy has a steep learning curve that requires unique skills which do not translate well from skills learned in other modalities, such as open surgery [11]. When performing laparoscopy, one is required to navigate a three-dimensional space on a two-dimensional monitor using unique instruments that often have limited degrees of freedom of movement [12]. For urology residents training in laparoscopy, the ACGME has placed the current requirement upon graduation to be 50 cases, although it is unknown if this is enough to be truly proficient at laparoscopy. Fortunately, there have been a number of laparoscopy-specific simulators created to help bypass the steep learning curve seen with laparoscopic surgery.

Basic Laparoscopic Skills

General Training

A number of unique skills are required to be proficient in laparoscopic surgery. One example is the requirement of good hand-eye coordination to achieve accurate movements while watching a monitor that is producing a two-dimensional image of a three-dimensional space. Given the amplification of small movements by the length of the instruments, manual dexterity is also very important. At the same time, there is the fulcrum effect of the body causing movements of the hands to mirror that of the instrument. These are just a few of the basic skills that must be mastered to be proficient in laparoscopy. Because of this, several simple bench models have been created that aim to help trainees master the basic skills of laparoscopy. In addition to acquiring skills, there is also evidence to suggest that practicing on a simulator prior to real surgery improves surgical performance [13].

The field of bench trainers (also termed "box trainers" or "video trainers") for laparoscopy is vast. There are many variations of trainers, with the basic premise of having a box through which instruments can be passed to perform a variety of tasks while using a camera to project the images onto a monitor. In their 2014 Cochrane review on the topic of laparoscopic surgical box trainers (limited to those with no prior laparoscopic experience), Nagendran et al. found an astounding 770 publications requiring screening, of which 32 were ultimately included on the topic [14].

Within the confines of a standard box trainer, a number of tasks can be performed depending on the desired skill to be practiced. The Fundamentals of Laparoscopic Surgery (FLS) simulator is one such box trainer that is considered by many to be the "gold standard" for the development of laparoscopic skills [15]. Based on the McGill Inanimate System for Training and Evaluation of Laparoscopic Skills (MISTELS), the FLS consists of five tasks: peg transfer, pattern cutting, ligating loop, extracorporeal suturing, and intracorporeal suturing. The complete program also has an online didactic portion. The FLS has been extensively studied, with all five tasks being validated, and proficiency on FLS has been shown to improve operative performance [16–19]. In fact, in 2009, FLS was added by the American Board of Surgery as a requirement before being able to sit for board examinations in general surgery [20].

Munz et al. have put forth a number of suggested tasks to be performed on box trainers that can easily be done at any institution [21]. To practice instrument navigation, Munz et al. had trainees conduct preset calculations on a calculator inside the box by using a pair of graspers. Coordination was practiced by placing a 30 cm piece of twine marked at 1 cm intervals with blue lines inside the box. Users then "walked" their way down the twine by only grasping at the lines. To practice grasping, a simple setup of two dishes can be placed inside the box, and objects can be transferred back and forth between dishes (chickpeas or small bolts are common objects to grasp). Cutting can be accomplished with a number of setups including grasping twine as above and cutting every centimeter on a marked line or cutting out along the lines of a circle drawn on a piece of cloth or examination glove. An added element of difficulty can be added to any of these tasks by timing the exercises and working on improving efficiency to improve times to accomplish tasks.

As evidenced above, box trainers allow many tasks to be practiced. An added benefit is that they're relatively simple to create. As such, there has recently been a publication on making a "homemade" lap simulator [22]. Using only a translucent storage box, an LED light source, and a webcam hooked to a monitor, Aslam et al. created a relatively simple and cost-effective box trainer. In their study of 34 trainees, 96.9% found the homemade box trainer to be satisfactory, and there was no significant difference in the completion of a variety of tasks on the homemade box trainer versus a commercially available model.

Box model training appears to improve technical skills of trainees, particularly in those with no prior laparoscopic experience. This was demonstrated in a recent Cochrane review [14]. The authors found in their meta-analysis that when comparing box model training to no training, those who used box trainers took significantly less time to complete tasks (0.54 standard deviations (SD) lower), they made less errors (0.69 SD lower), they had better accuracy scores (0.67 SD higher), and they had overall higher composite scores (0.49 SD higher). The authors also noted that there appears to be no significant difference when comparing the skills obtained on any one box trainer versus another [14].

Training of basic laparoscopic skills is not limited to box trainers. With the ever-increasing advances in technology, virtual reality has become an increasing popular option for skill acquisition and surgical simulation. Of all the VR simulators, MIST-VR (Minimally Invasive Surgical Trainer, Virtual Reality; Virtual Medical Presence, UK) is likely the most studied. First described in 1997, the MIST-VR is a computer-based system that consists of a frame holding two laparoscopic instruments whose movements are tracked and translated into virtual reality movements displayed on a standard monitor [23]. A foot pedal is also present to control simulated diathermy. MIST-VR allows users to work through a series of surgical tasks of increasing complexity, with an emphasis on developing the unique skills stated above that are necessary to perform laparoscopic surgery proficiently. Based on its numerous validations from several studies, MIST-VR has been integrated into many training programs around the globe [24]. Many of these studies have shown MIST-VR to demonstrate both construct and face validity [25–31].

A slight modification to the MIST-VR is EndoTower (Verefi Technologies, Inc., Elizabethtown, PA). EndoTower is additional software that can be downloaded onto the MIST-VR computer system and also requires a slightly different handpiece. A specific focus of the EndoTower is the use of the angled laparoscopic camera, which has been known to create problems with novices because of its off-axis viewing. EndoTower creates a virtual tower that serves as an obstacle course for users to navigate and find hidden objects [29]. In a study by Ganai et al., training on the EndoTower was found to significantly improve the performance of third-year medical students on a porcine navigational assessment with better object visualization and scope orientation scores than controls ($p < 0.05$) [32].

Released in 2002, the LS500 (Xitact, Switzerland) was a groundbreaking virtual reality simulator that combined haptics with high-fidelity simulation software. A focus of the LS500 was on laparoscopic cholecystectomy, and it has been validated in a number of studies [33–35]. It was from the LS500 platform that LAP Mentor™ (Simbionix, Cleveland, OH) was launched in 2003. Now on its third edition, the LAP Mentor is a validated VR laparoscopic simulator that has expanded from a number of laparoscopic-specific tasks to include modules on a number of operations [36]. The LAP Mentor helps develop many basic laparoscopic skills, such as translocation of objects, camera manipulation, clip applying, clipping and grasping, cutting, and a variety of two handed maneuvers. Several skills necessary for suturing can also be learned on LAP Mentor, including needle loading, knot tying, interrupted suturing, continuous suturing, and more advanced techniques such as the "backhand" technique and anastomosis suturing. Because FLS is considered the "gold standard" for laparoscopic training, Simbionix set to mirror FLS with the introduction of the "essential tasks module." Included in this module are peg transfer, pattern cutting, and placement of ligating loop, as are seen in the FLS program. In a study by Pitzul et al., the LAP Mentor "essential tasks module" demonstrated moderate concurrent validity with FLS, suggesting construct validity [15].

While both box trainers and VR simulators have their own merits, it is natural to question if one modality is better than the other. Gurusamy et al. did a meta-analysis of all studies that directly compared VR training versus box trainers and found two studies that attempted to answer this question [37]. The first study found operative time was significantly shorter for the VR group compared to the box-trainer group, but there were no reported numerical values ($p < 0.004$). In the second study, the VR group was found to have a 36% improvement in terms of operative performance versus 17% for the box trainer group ($p < 0.05$) [38]. Given the low power in these studies, as well as the few number of studies that compare between the two simulation modalities, the question of superiority of training continues to go unanswered. This question also becomes more complex when considering cost-effectiveness. This will ultimately require further studies.

Adrenal and Kidney

Clayman and coworkers performed the first laparoscopic nephrectomy in 1990. Since then, laparoscopy has found its way to nearly every indication for renal surgery. In contrast to open surgery, laparoscopic renal surgery has been found to decrease hospital stays and postoperative pain and improve cosmesis without sacrificing surgical outcomes [39–42]. One could argue that the majority of renal procedures done today, including radical nephrectomy, partial nephrectomy, and pyeloplasty, should be performed with laparoscopy or robotics.

Radical/Partial Nephrectomy

There are many current simulation options specific to radical and partial nephrectomy, many of which have been validated in a number of studies. The simplest is a bench model out of the University of Western Ontario. Using a commercially available polyvinyl alcohol (PVA) powder (Air Products and Chemicals, Inc., Allentown, PA), researchers were able to create a PVA liquid that could be poured into a custom mold and freeze-thawed into a renal model. Once the model was made, tumors could be suspended within the mold using a custom tumor mold [43]. The model was initially created for practice in renal ablative therapy, but now the model has now been expanded to use for partial nephrectomy. A unique feature of this model is its echogenic properties when scanned with an ultrasound probe, allowing trainees to use ultrasound to define tumor borders before simulating laparoscopic partial nephrectomy (LPN). Fernandez et al. studied the model's utility in LPN by having the model placed within a standard laparoscopic box trainer and having five MIS fellows do ten LPNs each. In the study, participants successfully identified 98% of tumors in a mean time of 1.12 min using a 7.5 MHz laparoscopic ultrasound probe. The researchers also found that positive surgical margins increased in the first three cases of each fellow, but steeply declined until none of the fellows had positive margins on their ninth and tenth cases. This model was recommended by four of the five fellows for training in LPN [44]. Abdelshehid et al. further expanded this model when they created an entire case scenario surrounding LPN. They created a simulated operating room (OR) environment with other team members including anesthesia, circulators, surgical assistants, pathologist, and scrub technician. Nine urologists underwent a simulated LPN, using the PVA kidney model with a 3 cm exophytic tumor placed within a standard box trainer and the SimMan 3G mannequin simulator. The authors found that the simulation-based team training was not only beneficial for its surgical simulation but also because it allowed multiple team members to practice and prepare for a complex surgery with an emphasis on improved communication [45].

Using a bench model for laparoscopic radical nephrectomy (LRN), Lee et al. created a scenario in which urology residents were told to do a LRN, but the case was complicated by a renal hilar vessel injury [46]. To create the scenario, the authors placed a commercially available rubberized kidney part-task trainer (the Chamberlain Group, Great Barrington, MA) inside a standard box trainer. Standard silicone IV tubing and a half-inch Penrose drain were passed into the hilar region of the model to simulate the renal artery and renal vein, respectively. Irrigation fluid dyed red to resemble blood was then hooked up to both sides of the IV tubing and Penrose drain. The fluid was placed under pressure to allow for brisk bleeding. The model was then draped to hide all irrigation tubing. Residents were unaware there would be any vessel injuries, which were two 1 cm lacerations made to the superior portion of the renal vein (Penrose drain). When users began ligation of the renal artery (IV tubing), the water irrigation system hooked to the Penrose was initiated, creating "venous bleeding." The residents then had to deal with the injury in any way necessary. Endpoints of the study were complete hemostasis or a 2 L blood loss. All eight of the residents (PGY-2 to PGY-5) were able to complete the exercise before the 2 L blood loss endpoint. Senior residents (PGY 4–5) were found to perform significantly better than junior residents (PGY 2–3) in terms of task-specific checklist scoring (75.0 vs 57.9, $p = 0.004$), global rating scale (4.00 vs 1.75, $p = 0.002$), and "blood loss" (462 vs 1075 mL, $p = 0.022$), suggesting construct validity.

Animal models also represent a viable and frequently used modality for surgical simulation. Often, animal models are used in proof of concept studies to demonstrate new surgical techniques and instruments. Some of the more popular laparoscopic simulation models are porcine models as the pig abdominal cavity is of similar size and has comparable anatomy to humans. In addition to porcine models, rabbit models are also sometimes used for laparoscopic nephrectomy simulation. Molinas et al. studied ten gynecologists and ten medical students in a rather large study of 200 laparoscopic nephrectomies on live rabbits [47]. Participants were evaluated during laparoscopic nephrectomy using standard laparoscopic instruments on live rabbits. Each participant performed a total of 20 nephrectomies, and the study found that both the gynecologists and students improved performance when comparing his or her first nephrectomy to the last. Overall time to perform the surgery decreased for students from 44 min to 11 min and from 29 min to 11 min in the gynecologists, with the gynecologists having significantly shorter operation times for the first nephrectomy ($p < 0.0001$) but not significantly different for the last. The students also had more episodes of heavy or mortal bleeding than the gynecologists ($p = 0.0003$), but both groups significantly improved in this category until no bleeding episodes were seen in either group after the 15th nephrectomy for each participant.

There are several virtual reality simulators for laparoscopic nephrectomy, with the Procedicus MIST™ (Mentice AB, Sweden) nephrectomy VR simulator remaining the most thoroughly evaluated [5]. The Procedicus MIST™ is a VR simulator launched in December 2007, which simulates both retroperitoneal and transperitoneal LRN. The simulator uses a standard computer, three foot pedals, haptic devices with instrumentation, and two monitors—of which one is touch screen [12]. Because of Xitact™ Instrument Haptic Port devices, the simulator allows the user to “feel” tissues, adding realism. Using a number of metrics to evaluate user performance, the LRN simulation is divided into three separate tasks. The first task is dissection and transection of the ureter, beginning with the user in the retroperitoneum after balloon dissection, at which point they must identify the gonadal vessel and ureter, dissect the ureter from its adventitia, and divide it. The second task is dissection of the hilar fat to identify the renal vessels, which then must be further dissected and divided. Adding reality to this VR model, the perihilar fat and renal vessels are capable of bleeding. The final task is complete dissection of the kidney. The Procedicus MIST™ was first validated by Brewin et al. in a study of eight experts, ten urology residents, and ten students. Face validity was demonstrated with the experts rating all components of the simulator ≥ 3 on a 1–5 Likert scale of realism, with particular emphasis on realistic graphics (mean 3.9) and instrument movements (mean 3.8). The simulator also demonstrated construct validity, with it being able to differentiate the experts, trainees, and novices by assessing hemorrhage (experts 236 mL, trainees 377 mL, and novices 1110 mL; $p < 0.01$), errors (181 vs 294 vs 419, $p < 0.01$), task time (1310 vs 1459 vs 2240 s, $p < 0.01$), and instrument travel (24.5 vs 28.4 vs 37.0 m, $p < 0.01$). However, Wijn et al. contrasted the study performed by Brewin et al., finding that the Procedicus MIST™ did not distinguish between intermediate (<10 LRN performed)

Fig. 24.4 Currently available commercial ureteroscopy simulators, (**a**) Uro-Scopic Trainer, (**b**) URO Mentor, (**c**) Scope Trainer [137]

and experts (≥10 LRN) and, therefore, was "not suitable for implementation in a urologic training program" in its present form [48].

Recently created, there are now patient-specific simulations that allow surgeons to rehearse before surgery. Makiyama et al. first developed this technology, in a study in which they successfully generated a VR simulator with specific patient anatomy (Fig. 24.4) [49]. The simulator uses dynamic CT images (1 mm slice early phase CT on 64 detector spiral CT) of the patient of interest, and a complex model data generator then extracts anatomic information and enters it into the simulator. The simulator allows for both transperitoneal and retroperitoneal approaches, and the kidney moves according to positioning (supine vs lateral). The simulator allows the surgeon to place the trocars and camera anywhere on the body, allowing generous autonomy on deciding one's surgical approach. Once trocar placement has been decided, users can use a number of instruments including forceps, Maryland dissectors, scissors, hook device, clips, laparoscopic stapling devices, and entrapment bags. A foot pedal allows for the use of simulated electrocautery, and a scope handled by an assistant can be changed between 0°, 30°, and 45° lens. The simulator also includes haptics, giving tactile feedback. Realistic bleeding is also included with the simulator, with the degree of bleeding depending upon the injury and type of vessel involved. Surgeons have the option of achieving hemostasis with gauze, forceps, or clips. In a follow-up study by Makiyama et al., face and content validity of the simulator was demonstrated in 13 preoperative simulations (7 nephrectomies, 4 partial nephrectomies, and 2 pyeloplasties) carried out by three surgeons [50]. On a 1–5-point Likert scale, the surgeons rated anatomical integrity to be 3.4 ± 1.1 (face validity), utility of the simulations to be 4.2 ± 1.1 (content validity), and confidence during subsequent surgery to be 4.1 ± 1.1.

Pyeloplasty

There are five procedures currently identified by the American Urological Association's (AUA) Laparoscopic, Robotic, and New Surgical Technology (LRNST) Committee for which simulation would be beneficial [51]. One of those procedures is laparoscopic pyeloplasty (LPP). LPP is done most often for ureteropelvic junction (UPJ) obstruction. This is a technically challenging procedure when done laparoscopically because it requires excision of the UPJ obstruction, spatulation of the renal pelvis and proximal ureter, and suturing of the anastomosis—all which must be accomplished intracorporeally. Without surprise, the learning curve for laparoscopic pyeloplasty can be steep for beginners [52].

Currently, the simulation options available for laparoscopic pyeloplasty include bench and animal models. The Simulation PeriOperative Resource for Training and Learning (SimPORTAL) from the University of Minnesota is responsible for the creation of a number of surgical simulation models. One model is a high-fidelity physical renal pelvis/ureter tissue analog bench model that allows for simulation of laparoscopic pyeloplasty. Using organosilicate-based materials, Poniatowski et al. created the pyeloplasty simulation model by 3D printing a patient-specific mold [51]. The renal pelvis is approximately 6 cm in the superior-inferior direction and 3 cm in the anterior-posterior direction, with an attached 18 cm ureter with 0.8 cm diameter. The UPJ obstruction has an outer diameter of 0.5 cm with an inner diameter of 0.2 cm. The model can then be placed in a standard laparoscopic box trainer, and the procedure can be performed. Additionally, the creators of this model integrated lines going down the length of the model that can only be seen under UV light. These lines allow for Black Light Assessment of Surgical Technique (BLAST™) to be done after the exercise, specifically looking for alignment of the UV-sensitive lines, indicating proper alignment of the UPJ anastomosis. Poniatowski et al. demonstrated face, content, and construct validity of the pyeloplasty model in a study of 31 attending clinical urologists. Face validity was demonstrated with a questionnaire given to participants after using the

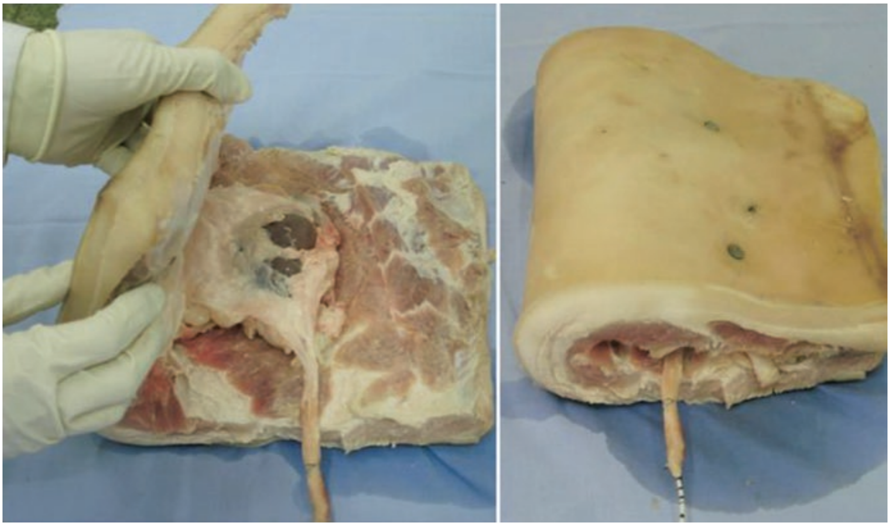

Fig. 24.5 Ex vivo porcine kidney wrapped in full-thickness skin flap [165]

model with participants giving the model an average score of 4.17 on a 5-point Likert scale for anatomical accuracy of the renal pelvis, ureter, and UPJ obstruction. Scores of 4.42 and 4.33 were given for the model reproducing skills for the anastomotic suturing and reproducing the skills of spatulation, respectively (content validity). Construct validity was shown as those who had experience in performing a LPP in the previous 5 years performed better than those who had not in terms of increased patency ($p < 0.05$), decreased twisting ($p < 0.05$), and decreased leakage ($p < 0.10$) [51].

A simpler model is the "latex glove" laparoscopic pyeloplasty model set forth by Raza et al. [53]. The authors used a standard latex glove with a knot tied at the base of one of the fingers to create a model in which the knot represents a strictured UPJ and the palm represents the dilated renal pelvis (Fig. 24.5). The model was placed within a standard laparoscopic box trainer, and a laparoscopic dismembered pyeloplasty was then performed. In their small study of five participants ranging from an experienced surgeon (>20 laparoscopic pyeloplasties) to an inexperienced medical student, Raza et al. touted construct validity for this model. The more experienced participants were found to perform the procedure in significantly less time (47 vs 160 min, $p = 0.043$) and with better suturing [53]. Further studies into the applicability of this model into urological training are yet to be seen.

Yang et al. have set forth a benchtop model for the simulation of a retroperitoneal laparoscopic dismembered pyeloplasty [54]. The model consists of a kidney made of commercially available plastic clay (such as Play-Doh®) with the middle part of the model being imbedded with a metal clip, allowing for the attachment of a carp swim bladder, to simulate a dilated renal pelvis. A separate 10 cm portion of porcine ureter is used as the model ureter, with it already being connected, as if the UPJ obstruction had already been excised. The model is then placed within a box consisting of five hinged boards, which can be adjusted to mimic the limited working space of the retroperitoneum. As would be done with a standard box trainer, the box is then used with standard laparoscopic equipment. The authors found in a cohort of five surgeons that operative time significantly reduced after using the trainer (41.84 vs 25.04 min, $p < 0.01$) and the surgeons rated themselves better on a general self-efficacy score (22.20 vs 27.60, $p < 0.01$). The authors also compared complication rates of the surgeons in real patient cases before and after simulation. Analyzing 15 patients prior to simulation for an average of 6.6 months follow-up, one patient experienced a restenosis and another patient experienced a prolonged urine leak. They then compared this to a group of 15 additional patients, followed at an average of 7.4 months after model simulation, and found there were no reported complications [54]. However, it is unclear if this study was powered to be able to detect significant differences in complications.

Animal models are also available to simulate LPP training. Ramachandran et al. were the first to describe the unique anatomy of the chicken esophagus to simulate LPP by using the chicken crop and esophagus to simulate the renal pelvis and ureter, respectively [55]. The crop of the chicken is a dilated segment of esophagus proximal to the stomach that primarily functions in food storage. Ramachandran et al. exposed the crop and esophagus of a dead chicken and then cleaned and filled the crop/esophagus with water to simulate a dilated renal pelvis. An 8F feeding tube was then passed down the esophagus into the crop, and the esophagus was ligated with a silk suture. The model was then placed into a standard box trainer, and a dismembered LPP was performed. Three urology residents initially studied this model in their final year of study, with each resident doing four LPPs over the period of a month. The study found that at the first attempt, only one of the three residents could complete the task because of technical difficulties experienced during laparoscopic suturing. However, after the fourth attempt, all the subjects could complete a good quality LPP in a mean time of 67.7 min, with each attempt taking less time and with better anastomosis suturing scores [55]. Jiang et al. then went on to demonstrate construct validity for this model in a separate study of 15 participants divided into three groups based off of experience. Participants were studied on the time to completion, as well as with a quality score on a scale of 1–10 assessed by a blinded evaluator (exact tissue sutured, equality of bite sizes, equal stitch intervals, lack of tissue tear, and water-tight anastomosis). The study found that the model was able to distinguish level of experience both by time to perform the task (33.80 min for experts vs 55.20 min for limited experience group vs 92.60 min in no experience group; $p < 0.001$) and in regard to a quality score (9.0 vs 7.2 vs 4.0; $p < 0.001$) [56].

There is one model currently described that uses live animals for LPP. Fu et al. were able to perform 60 LPPs (each side done three times) on ten anesthetized Guangxi Bama minipigs (20–30 kgs) using their own specialized proposed method [57]. Ten hours before surgery, the pigs fasted and underwent bowel preparation and then were placed under anesthesia and placed supine on an operating table. After getting access in a standard laparoscopic fashion, the renal hilum was exposed, and the ureter was divided close to the hilum and spatulated. Next, a piece of small bowel adjacent to the renal hilum was selected as a surrogate for an enlarged renal pelvis. The lower portion of the small intestine was then cut open, and after an antegrade stent was placed down the ureter, the "pyelotomy" was sutured to the previously spatulated ureter. Fu et al. studied this model with five trainees in an advanced laparoscopic urology fellowship, with each subject completing 12 LPPs over a 10-day period. The authors found that operative time significantly reduced after the trainees had performed 12 LPPs (135 vs 62 min, $p < 0.001$), and all subjects commented that the simulation was helpful and improved their laparoscopic skills [57].

Prostate

Urethrovesical Anastomosis

Since its introduction in 1997, the laparoscopic radical prostatectomy has largely been abandoned in favor of using robotic-assisted laparoscopy [58]. This is attributable to the extreme difficulty of intracorporeal suturing and knot tying deep within the pelvis, particularly the urethrovesical anastomosis (UVA), when performing with straight laparoscopy. Thus, there have been models created to help simulate and improve the skills needed to perform this task.

There are currently three described bench models for simulation of the UVA, two of which include animal tissues. The first is a relatively simple model introduced by Nadu et al. [59]. The authors used pieces of chicken skin available at local supermarkets to fashion a urethra and bladder that could be sewn together in a laparoscopic box trainer. This was accomplished by fashioning the chicken skin into a 4 cm tubular structure (urethra) over a 16F urethral catheter. The bladder is created by folding over a piece of chicken skin and cutting a 1 cm orifice in the folded edge. The model is then secured into a standard box trainer, and a UVA can be simulated at that time. Nadu et al. found in their initial study that two advanced laparoscopy urology fellows substantially reduced the time required to perform the anastomosis, from 75 min initially to 20 min after performing 20 UVAs on the model [59]. These results were confirmed in a subsequent study by Yang et al., suggesting this simple model may at least help improve operative time in performing the UVA in a laparoscopic radical prostatectomy [60].

A second bench model, described by Sabbagh et al., introduced a low-fidelity model for perfecting the UVA. This very simple model consists of a piece of latex tubing through which a Foley catheter can be passed and sutured to another piece of latex in the form of the bladder neck while placed in a standard laparoscopic box trainer. In their initial study, Sabbagh et al. randomly divided 28 senior surgery residents, fellows, and staff surgeons into two groups. The first group was the intervention group which practiced UVA on their low-fidelity model. Meanwhile, the second group practiced basic laparoscopic skills such as knot tying on a foam pad. The groups were later evaluated by a blinded grader on their ability to do five interrupted intracorporeal sutures on both the low-fidelity model and the foam pad. The study found that the intervention group scored significantly higher on a task-specific checklist (10.9 vs 8.1, $p = 0.017$) and global rating score (29.6 vs 22.8, $p = 0.005$) and in significantly less time (27.6 vs 38.3 min, $p = 0.004$) compared to the control group [61]. The authors subsequently published a prospective, single-blind, randomized study of their model in which the same cohort of 28 participants was again divided into the same intervention and control groups, but this time, the participants were evaluated on their ability to do a UVA on an anesthetized pig. Again, the group that trained on the low-fidelity model did significantly better than the control group in terms of checklist score, global rating score, and end product rating, demonstrating that skills acquired in a low-fidelity trainer can be translated to more “real-life” situations [62].

The third bench model is a combination bench-and-animal model simulating UVA, which has been proposed by Laguna et al. [63]. The authors used dead, plucked chickens that were at least 2.5 kilograms for their simulation. Using two subcostal incisions extended to the thighs, the authors removed all thoracoabdominal organs except for the esophagus and the stomach. An 18F catheter was placed through the esophagus, and the chicken was then placed within a Pelvic Trainer through which a standard laparoscopic camera and instruments could be used. Once in the box trainer, the specimen was transected completely at the gastroesophageal junction. In their study of the model, five urologists of varying experience (ranging from never having done a laparoscopic radical prostatectomy to >250 performed) were instructed to sew the UVA with two different suturing methods (six interrupted sutures vs running single-knot suture). The study found that suturing time and operator experience were linearly related ($r = -0.724$, $p < 0.001$) and that the most inexperienced surgeon significantly reduced the time required to complete the anastomosis with interrupted sutures (320.5 vs 146.7 s per stitch, $p = 0.001$) [63].

Female Urology

Sacrocolpopexy

Commonly performed by urologists with a focus in female urology, sacrocolpopexy is considered by many to be the “gold standard” procedure to repair vaginal prolapse. Sacrocolpopexy can be performed open, laparoscopically, or robotically, but as with many other surgeries, there is an increasing trend to perform this procedure more often in a minimally invasive fashion. However, with minimally invasive surgery comes with the added difficulty of laparoscopic suturing. Therefore, a model for laparoscopic sacrocolpopexy was created. Tunitsky-Bitton et al. created a simple bench model for laparoscopic sacrocolpopexy in which a RUMI Advanced Uterine Manipulation System (Cooper Surgical, Inc., Trumbull, CT) with attached sacrocolpopexy tip was covered with swimsuit material and placed within a standard FLS box trainer [64]. The authors studied this model with 5 experts (female pelvic medicine and reconstructive surgeons experienced with laparoscopic sacrocolpopexy) and 15 trainee participants (fourth-year gynecology residents and fellows). Participants used the model to perform the most difficult step of the laparoscopic sacrocolpopexy procedure—posterior mesh attachment. The authors found that the model demonstrated construct validity with experts performing significantly better than the trainee group in total score and every domain of the GOALS scale (33 vs 20.5, $p = 0.002$). Face and content validity was also suggested as 75% (all experts) "agreed" or "strongly agreed" that the model was realistic and useful for training laparoscopic sacrocolpopexy [64].

Robotic-Assisted Surgery

Robotic surgery, utilized by the urologic specialty more than any other, is an additional surgical tool that represents the next step up from laparoscopy. With it come a number of advantages over traditional laparoscopy, including improved ergonomics, instruments with "wrists," higher camera magnification, three-dimensional vision, and improved depth perception [65, 66]. Since it was first introduced, the number of robotic surgeries done around the world has grown exponentially. In 2014, Intuitive Surgical, makers of the da Vinci Surgical System (the only robotic surgical device in use today), reported 570,000 robotic cases had been performed [67]. However, with its incorporation, there is concern that many surgeons have been inadequately trained prior to doing robotic cases [67]. Even within residency programs, which are specifically designed to train residents, many residents feel inadequately prepared to perform minimally invasive surgery at graduation [68, 69].

Similar to the creation of the Fundamentals of Laparoscopic Skills curriculum, there has been the creation of the Fundamentals of Robotic Surgery (FRS), representing a push toward standardization of training in robotic surgery. They have formed a curriculum based around the development of basic robotic skills through simulation exercises that can be applied to a number of specialties. As the result of a conglomeration of 14 international surgical societies, FRS is the first consensus robotic curriculum [20]. Robotic simulation is similar to other surgical simulation modalities, consisting of physical models, animal models, and virtual reality.

Basic Robotic Skills

A cornerstone of the FRS program is the acquisition of basic robotic skills. These skills are absolutely essential to become a safe and proficient surgeon. For simulation purposes, the development of psychomotor skills is paramount, since it has been shown to have a steep learning curve. The FRS program has 10 tasks which teach 16 psychomotor skills. These tasks are FLS peg transfer, FLS suturing and knot tying, FLS pattern cutting, running suture, dome with four towers for ambidexterity, vessel dissection and clipping, fourth-arm retraction and cutting, energy and mechanical cutting, docking task, and trocar insertion task [20]. For simplicity, these tasks are all performed on a single device, the "FRS dome" (Fig. 24.6).

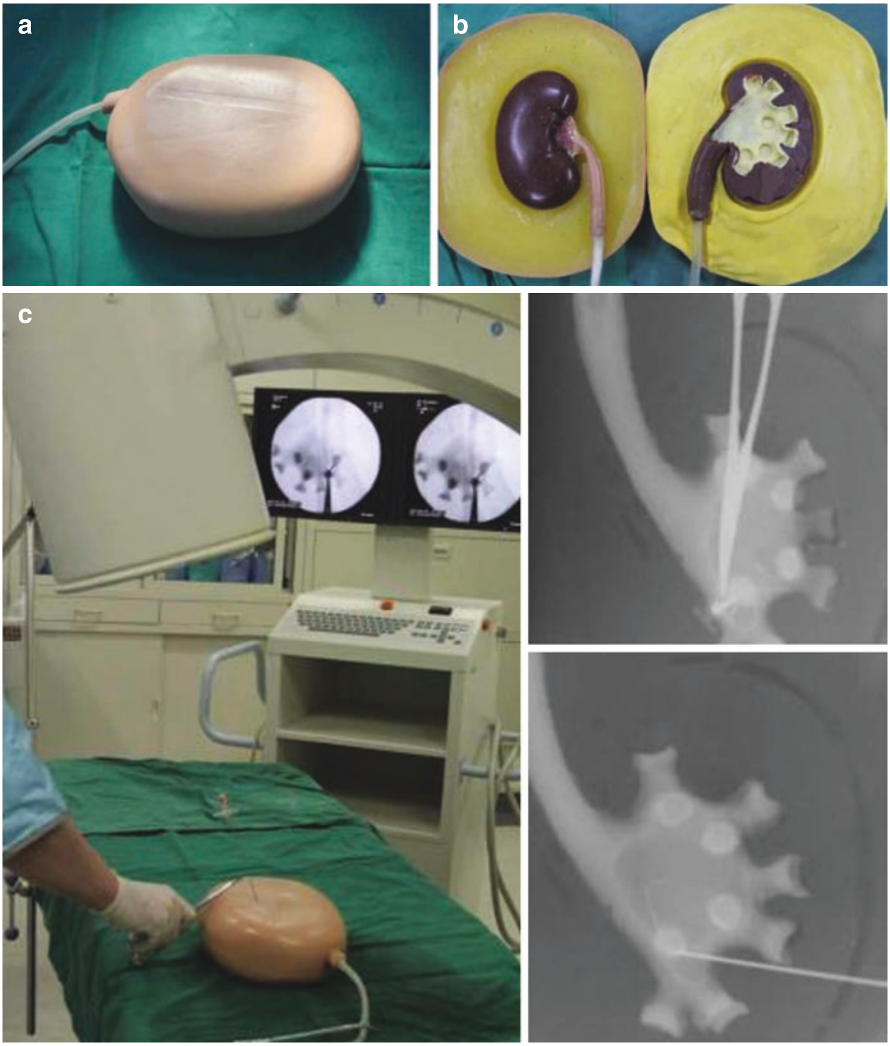

Fig. 24.6 Validated PCNL model compatible with both fluoroscopy and ultrasound [167]. (**a**) Practice of fluoroscopy guided PRA; (**b**) Puncture, C-arm at 20°; (**c**) Guidewire placement, C-arm upright

In addition to physical models, there have also been virtual reality simulations used in FRS to develop robotic skills. Robotic VR training has been dominated by three validated platforms: Robotic Surgical Simulator (Simulated Surgical Systems, Williamsville, NY), dV-Trainer (Mimic Technologies, Seattle, WA), and the da Vinci Skills Simulator (Intuitive Surgical, Sunnyvale, CA) [70]. The Robotic

Surgical Simulator (Robotic Surgical Simulator) and dV-Trainer are both standalone devices with hand controls and foot pedals designed to imitate the da Vinci robot, whereas the da Vinci Skills Simulator (dVSS) is a “backpack” to a standard da Vinci surgeon’s console where the trainee uses the console with a training interface [71]. All three simulators work on basic robotic skills including grasping, suturing, and psychomotor exercises such as peg transfer and letter-board tasks. Several studies are available that show validated face, content, and construct validity of all three simulators [71–77]. Hung et al. presented an interesting study in which the three platforms were cross-correlated by using structured inanimate exercises (bench models), the three VR simulators, and an in vivo robotic skills assessment on a porcine model [70]. The authors were able to confirm construct validity of each of the training tools and demonstrated that virtual reality performance was strongly correlated with in vivo tissue performance.

Adrenal/Kidney

There is currently very little that is published in the literature regarding simulation surgery on kidneys or adrenals for robotic surgery. This is hardly surprising, as robotic surgery has not been around as long laparoscopic surgery. There will likely be a movement to produce more kidney-specific robotic surgery simulations, as just like in laparoscopy a steep learning curve is present to master nephron-sparing robotic surgery. Mottrie et al. published that the learning curve of robotic partial nephrectomy for an experienced robotic surgeon is estimated to be approximately 30 cases to achieve a warm ischemia time of less than 20 min and improved complication rates [78].

Partial Nephrectomy

The first kidney-specific robotic simulation currently described comes from Hung et al. at the University of Southern California from 2012. They describe an ex vivo porcine kidney model with an embedded 1.5 inch Styrofoam ball, simulating a renal tumor [79]. The model was created by using a 1 inch melon scooper to score the renal capsule, with a 15-blade scalpel then used to create the defect, with care taken to avoid involvement of the collecting system. Once the defect was created, the commercially available Styrofoam ball was simply affixed within the defect with super glue (Fig. 24.7). The authors estimated that the model costs approximately 15 USD and took an average of 7 min to create. They studied this model in a group of 46 participants divided into experts, intermediates, and novices based upon level of robotic experience. The participants used a robot with Prograsp forceps and curved scissors (cautery and fourth robotic arm where not given) to excise the tumor (Styrofoam ball) with a clear margin of renal parenchyma (Fig. 24.8). The authors boasted excellent results with this cohort of participants, with experts giving the model a “very realistic” rating (face validity) and “extremely helpful” for training of residents and fellows (construct validity). The model was also able to distinguish between levels of experience with experts performing significantly better than intermediates and novices in overall score, time, depth perception, bimanual dexterity,

Fig. 24.7 Patient-specific VR simulator [50]

efficiency, tissue handling, and instrument and camera awareness [79]. However, the reality of blood loss and hemorrhage is not available with this model and poses a weakness to its use—especially for a model examining a procedure like partial nephrectomy.

Fig. 24.8 “Latex glove” laparoscopic pyeloplasty model [53]

Coming from the same group, a recently published simulation platform created for robotic partial nephrectomy was made that utilizes both augmented reality and virtual reality [80]. The authors created this simulation platform from the existing dV-Trainer platform. The first component of the simulator is augmented reality (AR) in which actual surgical footage is overlaid with virtual instruments which the user can manipulate. During this time, there is also narration from the operating surgeon, allowing for cognitive and technical tips to be learned by the user. The goal of the augmented reality portion of the simulation is to learn key aspects of the procedure via a number of interactive exercises. The simulation is divided into five modules each representing a key aspect of the procedure (colon mobilization, kocherization of the duodenum, hilar dissection, kidney mobilization, and tumor resection and repair). In the final module, there is an imbedded virtual reality exercise in which the user performs renorrhaphy on a modification of a previously validated suture sponge exercise from the Mimic Simulation library. In their study of this new simulator, Hung et al. again divided 42 participants into expert, intermediate, and novice

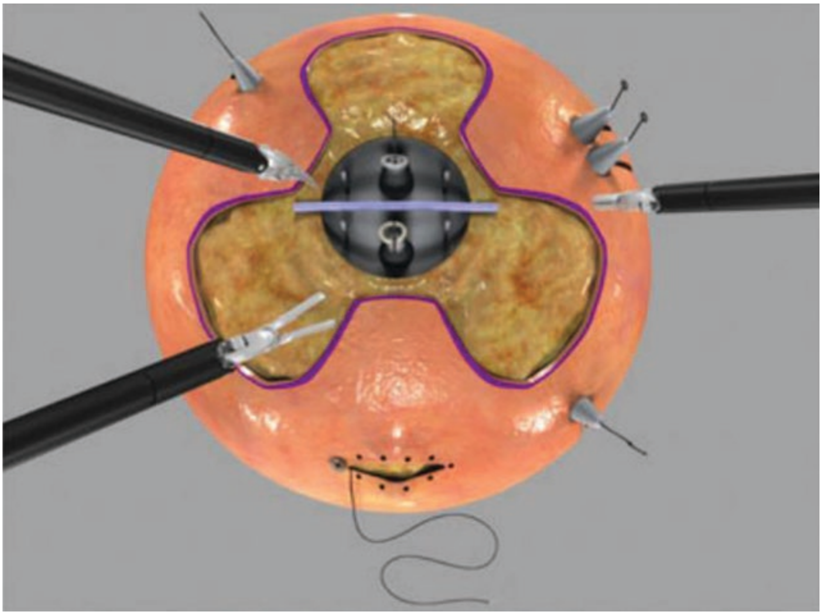

Fig. 24.9 Fundamentals of Robotic Surgery Dome for acquisition of basic robotic skills [20]

categories based upon robotic surgery experience. The authors found that the experts gave the simulation a median score of 8/10 in terms of realism (face validity). Experts also rated the platform highly in terms of its ability to teach relevant anatomy (9/10) and operative steps (8.5/10), suggesting content validity. Construct validity was suggested with experts performing significantly better than both novices and intermediates in a number of categories. Interestingly, the authors had the participants perform an in vivo porcine partial nephrectomy and found performance on the simulator correlated strongly with performance in the porcine partial nephrectomy ($r = 0.8$, $p < 0.0001$), demonstrating concurrent validity [80].

Bladder/Ureter

As with kidney simulation, there is currently little availability in the way of bladder- and ureter-specific robotic simulators. This may be a consequence of the relatively recent move toward doing more bladder/ureter procedures in a robotic fashion. Hung et al. have published a relatively simple cystotomy repair simulation in which a 2.5 cm incision is made on the anterior surface of a porcine bladder and a watertight closure is made using a robot [71].

Ureteral reimplantation represents a growing field in minimally invasive surgery, as minimally invasive techniques have been shown to have similar functional outcomes similar to those of open procedures [81, 82]. Despite its increased prevalence, ureteral reimplantation remains a relatively infrequently done procedure that may be lacking in traditional urologic training, particularly those done in a minimally invasive nature. As such, simulation-based training has been developed for this procedure. There is currently one validated ureteral reimplantation model described in the literature. This model consists of a plastic box which has a simulated bladder and ureter held in place by alligator clips (Fig. 24.9). The bladder and ureters are made of a commercially available hydrogel material (LifeLike BioTissue, Canada). The simulated bladder was created with a 12 × 15 cm rectangular piece of the hydrogel. The simulated ureter was created with hydrogel as well with a 0.5 mm wall thickness, 6 mm in diameter, and 15 cm in length. A 1 cm incision was made in the "bladder," and a 6F ureteral stent was passed through the ureter, and the anastomosis was then performed using a standard robot. Tunitsky et al. studied this model with 21 participants divided into "procedure experts" (>10 robotically assisted ureteral reimplant procedures performed), "robot experts" (fellowship-trained gynecologic surgeons with experience in a number of robot procedures), and "trainees" (fourth-year urology residents as well as urology and urogynecology fellows) [83]. After completing the simulation, all of the experts "agreed" or "strongly agreed" that the model was realistic and useful (face validity). Using a Global Operative Assessment of Laparoscopic Skills (GOALS) scale, the authors demonstrated construct validity by showing that procedure experts score significantly higher than both robotic experts and trainees ($p = 0.02$ and $p = 0.004$, respectively), and robotic experts performed significantly better than the trainees ($p = 0.05$). The authors have suggested that the model can be reused about ten times with an approximate cost of $22 (excluding stent and suture cost).

Prostate

Robot-Assisted Laparoscopic Radical Prostatectomy

The radical prostatectomy represents one surgery that has seen significant changes since the introduction of robot-assisted surgery. Because of the robot's ability for vision magnification and the use of small, long instruments which work well deep within the pelvis, there has been a dramatic shift in prostatectomies being done primarily open to now most being done with robotic assistance (RALRP) [84]. There have been multiple studies which have shown a rather steep learning curve for RALRP, with some suggesting that 250 cases may be necessary to gain proficiency at RALRP [85]. Increased experience with RALRP has been shown to result in fewer anastomotic strictures and a lower rate of cancer recurrence [86, 87]. As such, simulation training for RALRP has been developed to supplement the often inadequate RALRP exposure experienced during residency.

Alemozaffar et al. first described a unique simulation for RALRP in which a female porcine genitourinary tract tissue is fashioned into a male pelvic genitourinary model which can be used to simulate RALRP [88]. The authors started by making a plaster replica of the male pelvis with a fitted rubber pad to simulate the urogenital diaphragm. They then harvested the vagina, bladder, and ureters from a female pig. Through a number of steps, the porcine vagina was fashioned into a rectum and prostatic pedicle with the introitus becoming the prostate gland. The fallopian tubes were used to create seminal vesicles and the dorsal venous complex (DVC). Ureters were used to represent the neurovascular bundles running along the prostate. The recreated porcine anatomy is then placed into the pelvis model, which can then be used for simulation with a standard robot. The authors then had ten novices and ten experts perform the following steps of RALRP on the model: ligation of the DVC, division of the bladder neck, seminal vesicle dissection, ligation of the prostatic pedicle with sparing of the nerves, apical prostatic dissection with division of the urethra, bladder neck reconstruction, and UVA. The model demonstrated face validity with experts giving it a 3.7/5 score of realism, with a particularly impressive 4.5/5 for the UVA portion of the simulator. Experts also supported content validity with a score of 4.7/5 regarding the usefulness of the model for training of RALRP. Construct validity was demonstrated as experts performed the procedure significantly faster (60.8 vs 121.4 min, $p < 0.001$) and with significantly higher OSATS performance scores (4.6/5 vs 2.6/5, $p < 0.001$) [88].

While not a specific RALRP, Volpe et al. recently validated a curriculum specific for RALRP called the European Association of Urology Robotic Training Curriculum (ERUS curriculum) [89]. The ERUS curriculum was developed by a panel of experts in robotic surgery and consisted of 12 weeks of training divided into three stages: e-learning; an intensive week of simulation-based laboratory training including virtual reality, cadaveric, and animal simulations; and 3 weeks of supervised modular training in RALRP until they ultimately carried out a full RALRP. Despite being a small study of only ten urology fellows, the authors demonstrated that the training program resulted in significant improvement of the fellows' performance during RALRP, with 80% being deemed by their mentors as safe and effective to perform a RALRP independently after the training program [89].

Urethrovesical Anastomosis

As was discussed previously in the laparoscopy section, the urethrovesical anastomosis (UVA) is one of the most integral steps in a prostatectomy with a steep learning curve requiring surgeons to master intracorporeal suturing and anastomosis deep within the pelvis. As more and more prostatectomies are done robotically, there is a need for simulation for the robotic radical prostatectomy. By gaining proficiency in performing the UVA, one could go a long way toward becoming proficient at robot-assisted laparoscopic radical prostatectomy (RARP).

One such simulator is the virtual reality-based "Tube 3" module designed by Kang et al. [90]. The Tube 3 is a module specifically made for simulation of the UVA on previously discussed Mimic dV-Trainer (MIMIC Technologies, Seattle, WA). On the Tube 3 modules, users can perform a virtual reality UVA using a number of techniques, and scoring metrics are automatically tracked by the Mimic Technology. Kang et al. validated the Tube 3 module by dividing 20 urology attendings and residents into expert and novice categories and having them perform a UVA with a single-knot technique previously described by Van Velthoven et al. [90, 91]. The authors demonstrated face and content validity in which the ten experts answered questionnaires about the Tube 3 module. All of the experts "agreed" or "totally agreed" that the technical skills required to complete Tube 3 were compared to those that performed a UVA during radical prostatectomy. Eighty percent of the experts deemed it to be useful for training others to do UVAs and that it would be helpful in measuring proficiency at performing UVAs. Construct validity was also demonstrated with Tube 3's ability to distinguish the expert from the novice group. The experts performed significantly better than the novices in a number of categories including total task time, total score, economy of motion, and number of instrument collisions ($p < 0.05$). In a separate study, Kim et al. found the Tube 3 module to have concurrent and predictive validity by having 11 urology residents and fellows train on the Tube 3 module and then perform a robotic double bowel layer closure (concurrent validation) and a robotic UVA, both on commercially available models [92]. The authors demonstrated that participants who trained with the Tube 3 module were significantly faster to perform the above tasks than those who did not train on Tube 3.

A second described UVA simulator comes from the University of New York at Buffalo, which developed a haptic-enabled augmented reality-based training module for UVA. The system referred to as "HoST," hands-on surgical training, augments a real surgery with virtual reality components in which users are given audio and visual didactics of a given procedure (in this case, UVA) and then perform the steps themselves in the previously described Robotic Surgical Simulator. In a multi-institutional randomized controlled trial by Chowriappa et al., the HoST was found to improve technical skills for performing a UVA with little cognitive demand. Fifty-two urology residents and fellows (all with less than 25 h on a robotic console) were randomized to either the HoST training group or to control. All participants became familiar with the robot via fundamental skills of robotic surgery (FSRS) training on a RoSS console. The HoST training group then completed four, 20 min HoST modules, while the control group watched videos of UVA surgery for an equal amount of time. The groups were then scored on their ability to perform UVA on an inanimate model using a da Vinci robot. Face and content validity was suggested as 70% or more of the participants deemed the simulator to be realistic and would be helpful in learning to do UVA. The HoST group performed significantly better than the control group in terms of needle driving, needle positioning, suture placement, and on overall Global Evaluative Assessment of Robotic Skills (GEARS) score ($p < 0.05$) [93]. Participants also performed a NASA Task Load Index assessment, and the HoST group was found to have less temporal demand and effort and less mental fatigue than the control group ($p < 0.05$).

Endoscopy

Endoscopy has come a long way since Antonin Desormeaux excised a urethral papilloma using an endoscope with lighting from a kerosene lamp in the 1850s [94]. Endoscopy is perhaps now the most routine procedure performed by urologists, so a strong foundation of endoscopic skills is essential. Urologists have many tools at hand to perform endoscopy, most commonly using cystoscopes and ureteroscopes, which are made both rigid and flexible and in a number of sizes. Endoscopy is used for a number of procedures both diagnostic and therapeutic in nature; as such, a number of simulators for endoscopic procedures have been developed and will be discussed below.

Bladder/Urethra

Cystourethroscopy

Cystourethroscopy, occurring both in the operating room and in the office, represents one of the most commonly performed procedures by urologists. A rigid or flexible cystoscope is typically used to thoroughly examine the bladder and urethra in both males and females. There are currently several options for simulation of cystourethroscopy, including both bench models and virtual reality (VR) simulators. The URO-Mentor™ (Simbionix Corp, Cleveland, OH, USA) can be used for both flexible and rigid cystoscopy as well as ureteroscopy. The URO-Mentor uses a novel, sophisticated visual engine that is able to offer high-fidelity simulation with a number of features, including two- and three-dimensional rendering, collision detection, texture mapping, x-ray rendering, and special effects such as blood, smoke, and stone fragments [95]. In a study by Schout et al., the URO-Mentor system was used in training of flexible cystoscopy by both novice and expert endoscopists. The study demonstrated good construct validity and found that simulation with the URO-Mentor system resulted in large improvements in novice performance in terms of time, trauma caused, areas inspected, and global rating scale score [96]. In another study from the same group, study participants who received training on the URO-Mentor virtual reality system performed significantly better doing cystourethroscopy on real patients than those who did not receive VR training [97].

Despite the proven benefits that high-fidelity trainers and simulators provide, they come with significant cost, as new simulators often cost tens of thousands of dollars. It has been questioned if low-fidelity models could allow for the same learning experience for novices. Matsumoto et al. demonstrated that a low-fidelity model consisting of a Penrose drain representing the urethra, an inverted Styrofoam cup representing the bladder, and drinking straws inserted into the cup as ureters was just as effective for skill improvement in a group of 40 medical students when compared to a $3,700 high-fidelity model [98]. The same authors also presented a low-fidelity model of Styrofoam tubing, representing the urethra, leading into a bell pepper, representing the bladder, with 18 gauge Angiocaths puncturing the bell pepper, representing the ureters. This model has an advantage of a very low cost and the use of similar equipment used in the operating room, as trainees are able to practice cystoscopy and cannulation of ureters with various types of wires.

The use of cadavers in medical education is invaluable; however, there is scant literature available on using human cadavers in cystourethroscopy simulation. In one study from Bowling et al., they used fresh-frozen cadavers to assess cystoscopy skills in 29 OB/GYN residents. Various clinical scenarios were created, such as vaginal mesh eroding into the urethra. The residents were divided into a control group versus a study group who received training via a didactic session with bench models. The authors found that residents who underwent didactic training had significant decreases in scope assembly time and increases in task-specific checklists (92.9% vs 52.5%, $p < 0.001$) and global rating scores (87.8% vs 57.6%, $p < 0.001$) versus that of the controls [99]. Despite these benefits, cadavers are very expensive, cannot be used repeatedly, and can be difficult to obtain in various parts of the world.

Transurethral Resection of Bladder Tumor (TURBT)

Bladder cancer is one of the most common cancers in the world, with incidence increasing yearly. As such, transurethral resection of bladder tumor (TURBT) is one of the more common procedures performed by urologists [100]. There is a steep learning curve with inexperienced endoscopists performing TURBT. New learners are liable to inadequate inspection of the bladder, incomplete tumor resection, inadvertent bladder perforation, and/or increased bleeding. Additionally, patient outcomes have proven to be tied to experience, as inexperience with TURBT has been found to be a predictor of higher readmission rates and higher recurrence rates after TURBT for Ta and T1 tumors [101]. Therefore, TURBT represents a profitable target for simulation.

Currently there is one major TURBT simulator described in the literature, the Uro-Trainer® (Karl Storz GmbH, Tuttlingen, Germany) [102]. The Uro-Trainer is a VR simulator with both visual perception and haptic feedback, enabling users to resect papillary bladder tumors as well as carcinoma in situ (CIS) [102, 103]. The Uro-Trainer is commercially available and features a customary resectoscope, two flat screens, multiple instrumentations with varied resection loops, as well as laser instruments [103]. First presented by Reich et al., the Uro-Trainer was proven as a valuable teaching tool for both medical students and urology residents [104]. In a subsequent study, Kruck et al. demonstrated increased area of inspection (36.8–54.3%, $p < 0.05$) and improvements in resection rates (26.5% to 52.0%, $p < 0.05$) among novice endoscopists [103]. The Uro-Trainer was also used in this study to teach new techniques to experienced urologists. They found that experienced urologists gained significant improvement in both bladder inspection (52.2% vs 62.7%, $p = 0.003$) and resection rates (43.8% vs 57.1%, $p = 0.002$) with integrated photodynamic diagnostics (a type of fluorescence cystoscopy) versus standard white-light cystoscopy [103].

A second TURBT simulator was recently validated in the medical literature, the Simbla TURBT simulator (SAMED GmbH, Dresden, Germany). It is a high-fidelity simulator that has a resectable bladder with anatomical structures and embedded tumors within [105]. The Simbla model provides a realistic feel and scenario to trainees by allowing the use of standard OR instruments with connected monopolar or bipolar diathermy. It can also be connected to irrigation for continuous flow throughout the system. In an interesting study by de Vries et al., they identified 21 procedural steps and 17 pitfalls associated with TURBT. The Simbla simulator was found to cover 13 steps and 8 pitfalls. This simulator was found to have face, content, and construct validity [105]. Obviously, the major advantage of the Simbla model over its VR counterparts is its ability to use real instruments and irrigation.

Intravesical Botulinum Toxin Injection (Botox)

The use of intra-detrusor injection of Botox® (botulinum toxin) for overactive bladder was approved in 2011 by the FDA. This provided yet another new procedure to be learned by urologists. This procedure is done cystoscopically under local or general anesthesia with the goal to deliver an even distribution of botulinum toxin into the detrusor muscle, usually via 20–30, 1 cc injections [106]. There is currently only one VR trainer in the literature, which was developed at the University of Minnesota. Their system provides virtual bladder models of multiple sizes and bladder wall thickness, which allows learning of variable injection patterns with optimum penetration depth and dose control [106]. However, this simulator is currently not commercially available and is yet to be formally verified. Nonetheless, it presents a potential source of simulation for an increasingly more performed procedure.

Prostate

Transurethral Resection of the Prostate (TURP)

Transurethral resection of the prostate (TURP) is the classic, gold-standard procedure for the treatment of medically refractory lower urinary tract symptoms secondary to benign prostatic hyperplasia (BPH). However, as pointed out by Wignall et al., the learning curve to properly perform TURP is steep for several reasons. Users must work in a small three-dimensional space represented on a two-dimensional monitor, which requires substantial visual-spatial coordination [107]. This procedure is made more difficult as it is very common to experience intraoperative visual impairment from tissue and blood. Furthermore, serious adverse events can occur from this procedure, including urinary incontinence, erectile dysfunction, profuse bleeding, hyponatremia, and injury to a number of key structures including the urethra, ureter, or rectum [107]. Once a popular procedure is performed during residency, there has been a halving in the number of TURPs done by graduating urology residents over the last 15–20 years [107, 108]. Therefore, there is a demand for TURP simulators to help augment the learning of this procedure.

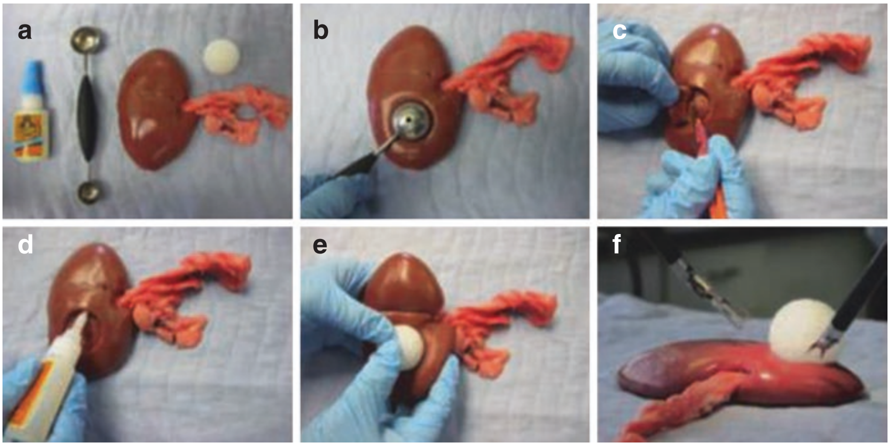

Fig. 24.10 Partial nephrectomy model proposed by Hung et al., (**a**) equipment used in model, (**b**) melon scooper used to score renal capsule, (**c**) a 15-blade scalpel is used to create a defect, (**d**) superglue applied to defect, (**e**) foam ball affixed to model, (**f**) excision of foam tumor [79]

TURP simulators can be broadly divided into high-fidelity virtual reality models versus non-virtual reality physical models—each with their own advantages and disadvantages. Physical simulators rely upon standard TURP equipment used on prostatic tissue surrogates, such as chicken breast, vegetable matter, or pig liver. Trainees at the authors' home institution use a standard TURP resectoscope with associated electrocautery capabilities in an OR-like environment with irrigation fluid and a standard endoscopy tower to resect portions of porcine liver. This model is particularly useful for more inexperienced trainees who can gain experience with assembling and using equipment likely identical to that used in the OR. The main disadvantage of this physical surrogate models is the lack of bleeding and other intraoperative complicating issues when resecting the tissue [109].

Another physical model, the Bristol TURP Trainer (Limbs & Things, UK), is a disposable bench model containing a synthetic prostate within a latex bladder on a plastic base [110] (Fig. 24.10). Trainees use a resectoscope with attached monopolar or bipolar diathermy to resect the prostate model, which is complete with irrigation fluid, realistic anatomy including ureteral orifices and verumontanum, and is made of a synthetic material that can be cut with the resectoscope diathermy loop. This is one of few physical models that has demonstrated face, content, and construct validity [111]. Advantages of this model are the lifelike anatomy, as well as the technical aspects it provides such as using actual resectoscopes, managing fluids, and handling resected prostatic chips. However, similar to other physical models, the Bristol TURP Trainer does not allow for bleeding or other potential complications of the procedure.

The first VR TURP trainer was developed in 1990 by Lardennois et al. Since its introduction, the use of virtual reality for TURP simulation has grown significantly [107, 112]. Many of the earlier models were limited in utility due to their lack of haptics, inaccurate deformation of tissues, and lack of bleeding [107]. Hemostasis was recognized as a critical learning point by Oppenheimer et al. in successful TURP training, so they developed simulated bleeding through the creation of a bleeding movie texture map library [113]. This subsequently initiated the creation of the University of Washington VR TURP trainer (UWTURP), in partnership with Gyrus/ACMI (Reading, Berkshire, United Kingdom), which has become the most extensively validated TURP trainer to date [111, 114]. Created in 2000, the UWTURP comprises a physical model of the penis and pelvis with digital recreations of urothelium and resection bed being based off of digital footage from actual TURP procedures. The simulator has the advantage of being able to track both motion and force data, allowing for objective measures of operative errors, blood loss, grams resected, irrigant volume, and amount of electrocautery use. Numerous studies have validated the model; thus, the UWTURP can successfully distinguish experts from novices. In a study by Sweet et al., no TURP experts had an operative error on a 5 min resection task, whereas novices resected the sphincter 50% of the time and 16% had to stop the operation because of blood loss making vision impossible [114]. Simulated practice with this heavily validated model is invaluable, as novices will learn from their mistakes in a simulated setting rather than harming patients during the early learning curve.

The PelvicVision TURP simulator is another VR TURP simulator that has shown construct validity in two small studies. This model consists of a modified resectoscope attached to a robotic arm, foot pedals, and a standard desktop computer [115]. The simulator gives haptic feedback as well as real-time tracking of variables such as resectoscope movements, blood loss, resection volumes, flow of irrigation, and operative errors, such as bladder perforation, resection of sphincter, and perforation of prostatic capsule. Källström et al. proved construct and content validity in a small study with this model that involved students. These students were able to demonstrate a positive learning curve and improving self-assessments in which they found the procedure to be easier with an increasing numbers of simulations [115].

Photoselective Vaporization of the Prostate (PVP)

Introduced in 1998, the GreenLight™ (American Medical Systems, Inc. Minnetonka, MN) laser photoselective vaporization of the prostate (PVP) has proven to be an effective treatment of bladder outlet obstruction secondary to BPH with significantly less morbidity than traditional TURPs [116–118]. GreenLight PVP uses a potassium-titanyl-phosphate (KTP) laser, of which it has a wavelength that is selectively absorbed by hemoglobin. Thus, tissue containing hemoglobin is preferentially vaporized with near instantaneous hemostasis [119]. AMS created a model, the GreenLight Simulator (GL-SIM), due to the popularity of GreenLight PVP. This simulator has shown both face and content validity [120]. The GL-SIM consists of a camera, scope, laser fiber, and foot pedal which are all pre-attached to a module. A standard laptop is used to run its VR software and display the video output. The system comes pre-loaded with five task-training modules, including anatomy identification, sweep speed, tissue-fiber distance, power settings, and bleeding coagulation. It also is pre-loaded with six full operative cases consisting of increasingly larger and more challenging prostates. Herlemann et al. have shown the GL-SIM to have face, construct, and content validity. Face and content validity was later confirmed by Aydin et al. [121]. They showed in their study that construct validity was demonstrated in two of the five training modules, as well as in operative time, errors made, and instrument cost [120]. Interestingly, Herlemann et al. found improved simulation outcomes in those that were able to play a musical instrument [121].

Holmium Laser Enucleation of the Prostate (HoLEP)

Similarly to PVP, Holmium Laser Enucleation of the Prostate (HoLEP) embodies an emerging alternative to the standard TURP. HoLEP uses a holmium:yttrium-aluminum-garnet (Ho:YAG) laser to enucleate entire lobes of the prostate via emission of pulsed 2140 nm energy [122]. There are some urologists stating that HoLEP has become the new “gold standard” for surgical management of BPH based on its efficacy and low morbidity [123]. However, due to its significantly different technique when compared to TURP, HoLEP has a very steep learning curve—much longer than that of a standard TURP [124]. This unfortunately is a major disadvantage of HoLEP and a reason that many in the urological community have not adopted

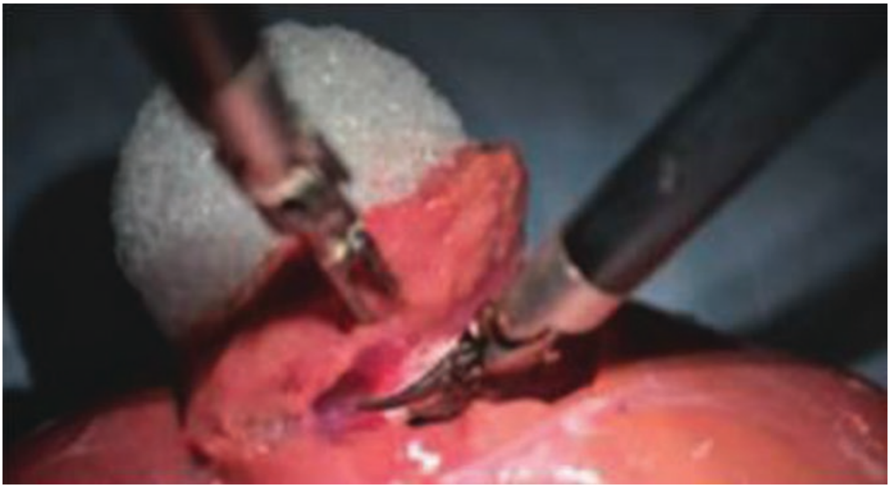

Fig. 24.11 Robotic-assisted partial nephrectomy foam ball excision operative view [79]

the technique [125]. Consequently, a bench-top model has been created to address this steep learning curve.

Developed by Kinoshita et al. and referred to as the Kansai Medical University HoLEP bench model [126], it contains a prostatic hyperplasia model that can be installed into a box simulator along with standard cystoscopic equipment and holmium lasers used to enucleate the model. Additionally, trainees are responsible for real-time fluid management to complete the procedure. The Kansai Medical University HoLEP bench model demonstrated face and content validity in a study of 36 participants by Aydin et al. [127].

There is a virtual reality simulator, the UroSim HoLEP simulator (VitraMed, Zurich, Switzerland), that has been developed and uses a cystoscope module connected to a computer system to simulate the procedure (Fig. 24.11). The simulator is equipped with haptic feedback and six different operative cases with varying anatomical variations and degrees of prostatic hyperplasia. In a study of 53 participants, Kuronen-Stewart et al. divided participants into three groups—novices, intermediate, and experts. The investigators were able to demonstrated face, content, and construct validity with significant differences in the enucleation efficiency, measured as grams enucleated per hour, between each group and a realism score of 5.6 out of 10 among experts [128].

Transrectal Ultrasound (TRUS) Prostate Biopsy

The TRUS-guided prostate biopsy currently is the gold standard to histologically diagnose prostate cancer. However, this relatively simple procedure is not without risk, with 0.69% of men requiring hospitalization to treat complications and reported mortality rates of 1.3% at 120 days [129, 130]. As such, there is a demand to develop simulators that could help bypass the early learning curve of the procedure and help avoid errors made in human patients. This is especially important given the more recent technology of targeted therapies for prostate cancer and the necessity for more accurate sampling of the prostate to avoid areas of untreated cancer.

It was at the University of Western Ontario where Chalasani et al. developed the first prostate biopsy simulator [131]. Simulator images come from a TRUS image bank that was created by collecting 3D TRUS images from 50 patients at the time of live biopsy. These images were incorporated into a mock pelvis which allowed for multiple simulated biopsies to be done with either a standard endfire or sidefire TRUS probe. Consisting of a rectangular box made using polyoxymethylene plastic, the mock pelvis is complete with dense elastic foam imbedded within to simulate the rectal wall as well as a tight elastic port of entry representative of the anus. The box can be manipulated such that simulated biopsies can be performed in either the left lateral decubitus or lithotomy positions. An embedded magnetic sensor tracks movement of the probe, and biopsies are fired with a foot pedal. Chalasani et al. demonstrated face, content, and construct validity in a small study involving 26 physicians; however, they did not reach statistical significance—likely because of the small sample size.

Recently, second prostate biopsy simulator has been created by Fiard et al. [132]. The simulator (unnamed, Grenoble University Hospital, Grenoble, France) is a laptop computer attached to a Phantom Omni haptic device and a stylus representing the ultrasound probe. Moving the stylus allows the user to explore the virtual prostate. Prostate images were obtained from human biopsy procedures. The software is also equipped with an evaluation system that evaluates users on their ability to accurately sample 12 sectors of the prostate. Fiard et al. demonstrated face and content validity in their small study 21 participants, consisting of 7 experts and 14 novices. The median rating of realism was remarkable, being rated 9/10 by novices and 8.2/10 by experts. However, construct validity did not reach statistical significance due to the small sample size, despite a 12% difference in scoring between novices and experts.

Kidney/Ureter

Ureteroscopy

Ureteroscopy (URS) incorporates an extensive range of multiple instruments used for a number of purposes. Some of the indications for URS include the management of upper tract urolithiasis, ureteral strictures, ureteropelvic junction (UPJ) obstruction, ureterocele incision/excision, upper tract biopsies, and ablation/excision of upper tract tumors. URS is accomplished with the use of either a semirigid or flexible ureteroscopes, of which there are many choices depending upon the manufacturer and the indication. With the ever-increasing incidence of urolithiasis in the United States, the incorporation of URS in the urologists' repertoire has also increased, especially since URS is a first-line treatment in stones <2 cm [133, 134].

There is not an established outcome currently for expertise of URS, but several studies on the learning curve for URS have used varying endpoints to estimate

Fig. 24.12 Robotic-assisted ureteral reimplantation model [83]. (*a*) Storage container 15 × 11 × 3 inches (approximately US $5); large bag clip (approximately US $3) attached with Velcro adhesive tape (approximately US $4), (*b*) alligator clips × 2 (approximately US $3) (*c*) twine (approximately US $5), (*d*) ureteral 6-F JJ stent, (*e*). **The cost does not include ureteral stent and suture

competence. Operating room time, total fluoroscopy time, stone-free rates, complication rates, instrument damage, and cost have all been used as surrogate outcomes in the measurement of a URS learning curve [135]. As such, there is a documentable improvement in the complication and success rates of URS with surgeon experience [135]. Making sure residents are well trained upon graduation from residency, the ACGME has placed a minimum number of 60 URS cases for graduating residents. However, they also note "the minimum requirement for procedures does not supplant the requirement that, upon a resident's completion of the program, the program director must verify that he or she has demonstrated sufficient competence to enter practice without direct supervision" (http://www.acgme.org/portals/0/pfassets/programresources/480-urology-case-log-info_.pdf). Consequently, teaching programs and their trainees are starting to become objectively measured. The Objective Structured Assessment of Technical Skills (OSATS), based on a 14-point curriculum, has been designed to assess the necessary cognitive and psychomotor skills of trainees, and it has indeed shown to correlate ureteroscopic performance with experience [136].

As discussed previously, there has been a push to augment training programs with simulators to potentially bypass the early error-prone learning curve of procedures. URS is a particular procedure that has seen significant innovations in simulation options over the last decade. Currently available URS simulators are broadly categorized into virtual reality, bench, animal, and human models (Fig. 24.12).

Regarding bench URS models, there are three main validated simulator models currently available. The first is the URO-Scopic™ trainer from Limbs & Things (Bristol, United Kingdom). The URO-Scopic™ trainer is a high-fidelity physical model that incorporates the training of standard semirigid and flexible ureteroscopes. The model includes a male pelvis with a urethra, bladder, bilateral ureters, and collecting systems [137]. Three studies have analyzed the URO-Scopic™ trainer. In the first study, Matsumoto et al. demonstrated construct validity of the model in a study of 17 urology residents, showing improved performance as evidenced by OSATS, pass rating, and time of procedure [138]. Mishra et al. further studied URO-Scopic™ by comparing URO-Scopic™ versus a VR simulator (URO Mentor™, discussed later). Lastly, in a study of 21 urologists with no experience in URS, the trainees gave URO-Scopic™ a realism score of 6.74/10, and users were found to improve their performance of URS via a global rating score system with each attempt at URS [139].

The second available URS bench model is the Scope Trainer (Mediskills Ltd., United Kingdom). The model is high fidelity, comprised of a distensible bladder and a single collecting system. The Scope Trainer has many helpful features, including a transparent dome that allows visualization of instruments within the model. Other features include reproduction of lumbar lordosis to enhance realism, a collecting system containing stones and papillary tumors, and a "percutaneous" access tract for antegrade passage of a scope. Two studies are currently available that evaluate the Scope Trainer, both performed by Brehmer and colleagues. In their first study, 14 urologists were observed and scored using a task-specific checklist when performing rigid URS on both patients and the Scope Trainer model. Impressive to note is that all study participants claimed the model was similar to surgery and that participants scored identically between human and model cases [140]. Predictably, the study participants who had underwent an endourology fellowship scored significantly higher than their counterparts on both human and model surgery (18.2 vs 16.8, $p = 0.0084$). In their second study, 26 urology residents used the Scope Trainer for semirigid URS. Participants on first use of the model recorded baseline scores, then they trained on the model under supervision, and then finally a post-training procedure was done. Baseline and post-training procedures were scored on a task-specific checklist and a global score (maximum = 19). Residents were found to significantly improve their skills from an average baseline score of 7.7 to a post-training score of 17.2 [141]. Notably, the Scope Trainer showed promise as a tool for improving URS manual dexterity skills. Construct validity was also demonstrated in this study, with experienced residents scoring an average total score of 17.6 versus an average score of 7.7 by inexperienced residents.

The third validated bench URS model is the "adult ureteroscopy trainer" (Ideal Anatomic Modeling, Holt, Michigan). White et al. used CT images of the upper tract of a patient who had difficulty spontaneously passing renal calculi to make their model via rapid prototyping, which involves the creation of thin, virtual, horizontal cross sections from animation modeling software to transform those virtual cross sections into a physical model. With this technology, they were able to essentially "clone" that patient's collecting system into a durable silicon mold. In their initial study of 46 participants, ranging from urology attendings to medical students, results were rather impressive. One hundred percent of participants rated the model as realistic, 98% thought it would serve as a good training format, and 96% recommended it for urology training [142]. Construct validity was verified with expert and novice endoscopists removing a lower pole calculus and being scored by a global rating scale and ureteral checklist, modified for absence of bladder and urethra. Expert endoscopists scored significantly better than their novice counterparts (33.1 vs 15.0, $p < 0.0001$) and performed the task in less time (141.2 vs 447.2 s, $p = 0.01$). The authors touted that the model cost $485, a bargain in comparison to other models—which can range from $3700 to $60,000! However, one notable limitation of this model is the lack of bladder and urethra, which eliminates the technically heavy steps of guidewire manipulation and cannulation of the ureteral orifice.

Recently a flexible URS model called the K-Box® (Porgès-Coloplast, France) was created and published [143]. The K-Box® consists of four independent boxes made of polyurethane and has a number of features not been seen in previous models. Each box allows a number of trays that can be swapped in and out, allowing for multiple configurations to challenge the user. The model uses a standard ureteroscope along with wires and baskets, and to assist users, the model's lid can be removed, and the scope's location can be seen, acting as a surrogate for fluoroscopy. The model allows users to practice tasks such as advancing guidewires, placing ureteral sheaths, and basketing stones. Trainees also have the capability to use water in the model, allowing the use of laser to fragment stones. The K-Box® seems to be a viable and potentially very useful model, but it still needs further studying in order to establish validity.

In contrast to physical bench models, VR model simulators use computer-based systems to simulate particular procedures. Preminger et al. showed the feasibility of a VR URS simulator in 1995, and since that time, the field of VR URS simulators has seen significant advances, particularly with the concurrent advances in technologies [144]. The most studied VR ureteroscopy simulator is the URO Mentor (Simbionix, Israel), which was briefly mentioned previously. The URO Mentor consists of a male pelvic mannequin incorporated with a Windows-based computer interface. The simulator allows users to practice with both flexible and semirigid ureteroscopes, which are passed through the interface device into the mannequin. Once inside the mannequin, the system converts movements that tracked multiple sensors into realistic images on the monitor. Additionally, the simulator also allows for realistic 2D fluoroscopic imaging during simulations. An array of virtual working instruments is available to users when using URO Mentor, including guidewires, baskets, forceps, stents, dilators, and a number of lithotripsy probes [95].

Michel et al. first described the URO Mentor in 2002, and since that time, there have been a number of validation studies performed [95, 137]. Their initial study aspired to demonstrate face validity, stating that both trainees and endourological instructors felt the URO Mentor displayed a high degree of realism, but their study was flawed in that they never disclosed how many participants were in the study nor how it was done [95]. However, there have been several other studies that have demonstrated construct validity for the URO Mentor simulator. Watterson et al. and Wilhelm et al. did similar studies in 2002, both of which verified construct validity. In their studies, they used 20 and 21 medical students, respectively, and randomized them to teaching on the URO Mentor system versus control groups. Both found that the trained participants did significantly better than the control groups (Watterson: global rating score 23.6 vs 14.7, $p < 0.001$; Wilhelm: 21.3 vs 16.1, $p < 0.001$) [145, 146].

Jacomides et al. studied the completion time of training modules on the URO Mentor for 16 medical students and 16 urology residents. They discovered that the students significantly decreased their completion times of the module after training on the URO Mentor for 5 h. However, they found no significant difference in the completion times among the residents. Notably, they found the medical students were able to complete the task in similar times to first-year residents, who had a median 14 clinical URS procedures after training [147]. This is significant in that medical students may be able to bypass the early learning curve and catch up to residents in terms of operating times by using the VR simulator. Matsumoto et al. further exhibited construct validity by assessing 16 urology residents using several parameters in the task of basketing a distal ureteral stone on the URO Mentor. Their study found that senior residents scored significantly better than junior residents in terms of global rating scores, examiner checklist assessment, pass/fail rating, time to complete task, and incidence of scope trauma [148]. In a study of 89 participants that consisted of both urologists and urology residents, Dolmans et al. found that URO Mentor scored a mean global realism score of 3.14 on a 1–5 Likert scale for URS. Eighty-two percent of participants rated it ≥3.5 on a scale of 1–5 in terms of usefulness as an educational tool. In this study, the overall rating for the URO Mentor on a 10-point scale (1 = poor, 10 = excellent) was 7.3 [149].

Criterion validity for URO Mentor has also been evaluated in multiple studies. The importance of criterion validity is that it helps answer the question if a simulator can effectively translate to improve clinical performance. Ogan et al. studied 16 medical students and 16 urology residents for criterion validity on the URO Mentor. Participants underwent a baseline evaluation on the URO Mentor, and the medical students underwent an additional 5 h of supervised training on the simulator. After the medical students received training, all participants then underwent a second evaluation on the URO Mentor in addition to a similar task on a fresh-frozen cadaver. The study found that the medical students significantly improved performance from their baseline assessment to their second simulated task, but they still underperformed against the residents in the cadaveric URS in multiple subjective and objective measurements. In terms of criterion validity, the student performance on the post-training simulation strongly correlated with performance on the cadaver in areas of time =, global rating score anatomy, and overall scores. Unfortunately, these correlations did not hold for urology residents. This suggests that the URO Mentor is helpful in predicting the performance of inexperienced endoscopists, but likely does not predict performance improvement for those with more experience [150]. Knoll et al. studied 20 urologists of varying experience in their performance in treating a lower calyceal stone. Cases performed ranged from 21 to 153. The authors found that those that had performed less than 40 URS cases scored significantly worse than those who had greater than 80 cases, thus exhibiting construct validity. Criterion validity was also proposed by comparing five inexperienced urology residents versus five inexperienced urology residents trained on the URO Mentor. When compared, they found that the simulator-trained group performed significantly better on their first four URS cases on humans, as assessed by operative times between the groups [151].

The use of live animals for surgical training is controversial. Therefore, ex vivo animal models are advocated by a number of authors. By using organs obtained from pigs already being slaughtered for food, legal and ethical issues have been essentially erased [152]. Looking for a more realistic feel than plastic models at the time, Strohmaier and Giese were some of the first authors to describe the use of an ex vivo porcine model [153]. They used an en bloc resection of all retroperitoneal organs (kidneys with ureters, bladder, urethra, aorta, vena cava, intestine, rectum, and anus) from freshly slaughtered adult pigs, with subsequent isolation of the urinary tract. The authors describe that 7.5–9 F ureteroscopes could successfully be navigated through the porcine GU system, giving more realistic and accurate tissue feeling than physical models. Subsequent authors have since described using similar porcine ex vivo setups [109, 154, 155].

Soria et al. did a validation study that was divided into three levels. During the second level of their study, an ex vivo porcine renoureteral unit was used for training of laser lithotripsy on a mid-ureteral stone. Their model demonstrated face validity in the study of 40 participants with a global realism score of 4.25 ± 0.13 on a 5-point Likert scale [156]. Unfortunately, further validation and data regarding educational value for ex vivo models are currently still lacking.

Percutaneous Access/Litholopaxy

Since being first described by Fernström and Johansson in 1976, percutaneous nephrolithotomy (PCNL) has signified a viable and increasingly popular way to manage complex renal calculi [157]. Due to further advances in technique since its inception, PCNL has essentially eliminated the use of open surgery in the removal of renal calculi [158]. However, PCNL is still a risky procedure with a high incidence of overall complications at 83% [159]. The most common complications include hemorrhage requiring transfusion, with overall mean incidence ranging 11.2–17.5%. Colonic or pleural injuries are highly associated with the access portion of the procedure. PCNL is also known for its steep learning curve. Current literature suggests that 36–45 cases are needed to become competent and 105–115 cases are needed to achieve proficiency for PCNL [160, 161]. Additionally, as few as 11% of urologists are able to obtain percutaneous access without the help of an interventional radiologist, which suggests that many trainees are uncomfortable or untrained in achieving percutaneous renal access [162]. As such, simulation in PCNL has become increasingly popular.

Fig. 24.13 UroEmerge™ Suprapubic Catheter Model with plastic trainer housing the simulated full bladder [6]

Four bench models of PCNL are currently described in the literature—three of them utilize ex vivo porcine renoureteral units. The initial model was described by Hammond et al. in which the authors placed pebbles within a porcine kidney/ureter, which was then placed inside a chicken carcass [163]. Urology residents were then taught needle access, guidewire placement, tract dilation, retrograde and antegrade pyelograms, renal access sheath insertion, and rigid and flexible nephroscopy with the assistance of fluoroscopy. This model has never been validated, but through anonymous surveys, it is suggested that trainees are satisfied with the model, allowing them to become more comfortable with the technique and equipment of renal access.

A second bench model, developed by Strohmaier and Giese, also used ex vivo porcine kidneys and ureters but in a considerably different way [164]. Calculi are placed into the cadaveric porcine renoureteral units via opening the collecting system and then secured by a watertight closure with a running suture. Then, ureters can be cannulated with catheters through which saline is instilled to mimic hydronephrosis. The model is then placed upon a rectangular silicone mold, and the entire setup is covered with liquid silicone, which takes approximately 3 h to solidify and lasts about 1 week. Trainees can then perform the usual steps to perform nephrolithotomy via ultrasound or fluoroscopic guidance into the collecting system. Other procedures and techniques that can be performed with this model include endopyelotomy, incision of calyceal neck stenosis, antegrade stent placement, and inserting percutaneous drainage catheters.

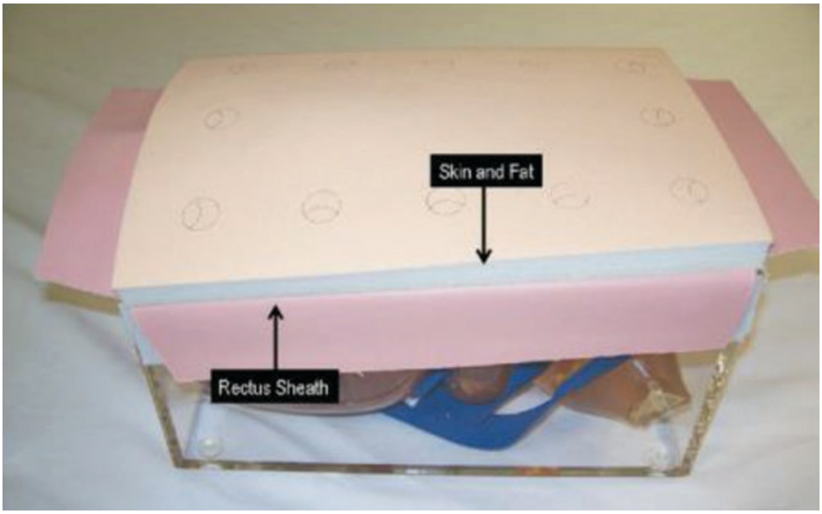

Fig. 24.14 UroEmerge™ Suprapubic Catheter Model contains an abdominal pad that simulates skin and rectus sheath [6]

A unique ex vivo porcine model was created by Zhang et al. in 2008 by wrapping a porcine kidney in a full-thickness skin flap complete with fascia and muscle (Fig. 24.13) [165]. Trainees using this model found it to be quite useful; however, the authors note that the 12th rib is an important anatomical landmark for percutaneous renal access. Therefore, they modified their model to incorporate a portion of porcine thoracic or abdominal wall that contained at least two ribs [166]. One hundred twenty-six urologists tried the modified model, and 90.5% rated the model as "helpful" or "very helpful" for simulation of PCNL.

Currently, there is a single validated PCNL bench model as described by Zhang et al. [167]. The model is 36 × 32 × 12 cm and composed of three components made of mixed silicon materials (Fig. 24.14). Consisting of a kidney with a dilated collecting system with an attached ureteral stump, the model is encased within simulated perirenal tissue of approximately 4 cm thickness. The goal of this model was to simulate the texture of the human body as much as possible. Similar to previous bench models, trainees can practice both fluoroscopy and ultrasound techniques on this model to obtain renal access. A significant advantage of this model was that multiple trainees could repeatedly use it as it is tolerant to multiple sticks for needle access; however, the cost-effectiveness of this model versus ex vivo animal models has never been studied. In their study, Zhang et al. demonstrated face, content, and construct validity for the model. Nine experts—considered experts as they've logged over 60 cases—and thirty novices were enrolled in the study and performed fluoroscopy-guided percutaneous renal access on the model. The experts rated the model an overall appraisal of 4 out of 5 points on a 1–5-point Likert scale, a score of 5 for utility as a training tool, and a score of 4 as an assessment tool, thus giving the model both face and content validity. Significant differences were found between experts and novices, with experts taking less total time (183.11 vs 278.00 s, $p < 0.001$), shorter fluoroscopy time (109.22 vs 183 s, $p < 0.001$), and fewer attempts (1.28 vs 2.35,$p < 0.001$), thus exhibiting construct validity. After two 1 h skills sessions on the models, novices significantly improved their total time (278.00 vs 189.93 s, $p < 0.001$), fluoroscopy time (183.13 vs 121.97, $p < 0.001$), and number of attempts (2.35 vs 1.43, $p < 0.001$). After extensive training, it was found that there was no significant difference in performance of the novices versus the experts in the aforementioned categories.

Similar to other procedures, a virtual reality simulator has been developed and validated for percutaneous renal access. The PERC Mentor™ (Simbionix, Israel) is one such simulator, which has a number of fascinating features. The PERC Mentor™ uses a torso mannequin linked to a computer-based simulation system. The mannequin can be added onto the previously discussed URO Mentor system and is considered a high-fidelity flank model, designed to provide haptics of skin, muscle, connective tissue, and ribs similar to real human tissue. A virtual C-arm and mock angiographic instruments are included with the simulator, allowing users to make percutaneous access under simulated fluoroscopic guidance that is controlled by a foot pedal. A metal needle containing a spatial sensor is placed through the simulated torso into a digitally projected renal collecting system. Contrast medium can be delivered through a ureteral catheter, and placement can be confirmed in real time with aspiration of "urine" from the collecting system. Unique to this model is its simulation on the displacement of organs with respirations, something that has not been feasible with bench models. A number of tasks and case scenarios are available, with difficulty ranging on a scale of 1–10. Endpoints are measured during tasks and case scenarios, including operative time, number of puncture attempts, fluoroscopy time, rib collisions, collecting system perforations, and vascular injuries [168].

Knudsen et al. initially validated the PERC Mentor™, where 63 novices, including medical students and inexperienced residents, used the PERC Mentor™ to learn percutaneous renal access [169]. Participants initially underwent baseline testing on the simulator, the goal of which was to gain percutaneous access into the kidney and pass a wire into the collecting system. Then the users were randomly divided into two groups. The first group underwent two 30-minute training sessions on the simulator, while the second group received no training. They then attempted to gain percutaneous renal access again but in a different case scenario, for which they were assessed using a global rating scale by the study evaluators as well as measured parameters collected by the simulator. The study showed that the two groups were insignificantly different at baseline, but after training, the intervention group significantly improved their performance on 11 of the 14 measured outcomes, but the untrained group made no improvements. Furthermore, the trained group performed significantly better than the untrained group on the posttest in all but two parameters—the number of rib collisions and the amount of contrast used on antegrade nephrostogram. Face validity was demonstrated because the high-fidelity flank model, fluoroscopy foot pedal, and realistic needle allowed all participants to effectively gain percutaneous renal access. The authors also asserted that content validity was demonstrated because the simulator was developed with the input of a number of experts in the field, who helped create the varied case scenarios, anatomy, and imaging data. The PERC Mentor™ also demonstrated construct validity by correlating the subjective global rating score with objective measures such as Spearman rank correlations, which helps to establish convergent validity. This was further validated by a follow-up study from Park et al., in which nine experts, comprising five urologists and four interventional radiologists, were compared against 63 novice medical students and residents on a case scenario using the PERC Mentor™ [170]. Construct validity was demonstrated due to the experts significantly outperforming the novices, as measured by the global rating score (24/25 vs 12/25). Experts rated the PERC Mentor™ very highly on five of six domains (mean 8.1 on 10-point scale), thus giving the model substantial face and content validity.

Achieving better performance in the operating room is the ultimate goal of any simulator. Termed predictive validity, Margulis et al. performed a follow-up study to the initial PERC Mentor™ validation study to see if users trained on the PERC Mentor™ performed better in the OR [171]. The authors used the same 63 novices from the initial study, for which they evaluated the trained and untrained groups in their ability to gain percutaneous renal access in anesthetized pigs. The study found that the trained group performed significantly better than their control counterparts in terms of number of punctures (1.9 vs 2.7, $p = 0.005$), number of infundibular punctures (0.3 vs 1.1, $p = 0.002$), and number of collecting system perforations (0.4 vs 0.8, $p = 0.003$) and scored higher on the global rating score (3.8 vs 2.7, $p < 0.001$). A crossover study was then performed in which the control group underwent training on the PERC Mentor™. This group was subsequently found to perform at a level with no statistical difference of the initially trained group. Although surgery on an anesthetized pig may not translate to operating on humans, the study still provides promising evidence that the simulator improves performance without putting humans in undue danger.

Recently described, an unvalidated hybrid simulator called the SimPORTAL (University of Minnesota) is an additional VR PCNL model. The SimPORTAL is a fluoro-less “C-arm” trainer that was paired with a transparent silicon flank bench model during its initial study [172]. This model unit consists of two webcams mounted onto a small C-arm that is produced with a 3D printer. The C-arm can be tilted (−30°/+30°) and rainbowed (−15°/+15°). The cameras are attached to a MacBook Pro™, and via a special video processing technique, the camera images are fused, overlaid, and processed to achieve a simulated x-ray image which can be seen on a screen by the user. In their initial trial study with 14 participants, Veneziano et al. found that 92.8% of participants found it to be of at least equal value to currently the PERC Mentor™ and as such warrants further validation studies [172].

Conclusion

Surgical simulation is an emerging field aimed at providing learners with an environment to sharpen skills in a setting that does not put patients in harm’s way. In the field of urology, the majority of procedures performed by a urologist have some sort of simulation with simulators being developed and validated for open, endoscopic, laparoscopic, and robotic procedures. Future advancements will aim toward increasing realism and applicability to real-life scenarios.

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