Novel Education and Simulation Tools in Urologic Training

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Abstract

Purpose of Review Postgraduate medical training has evolved considerably from an emphasis on hands-on, autonomous learning to a paradigm where simulation technologies are used to introduce and augment certain skill sets. This review is intended to provide an update on surgical simulators and tools for urological trainee education.

Recent Findings We provide an overview of simulation platforms for robotics, endoscopy, and laparoscopic practice and training. In general, these simulators provide face, content, and construct validity. Various educational and evaluation tools have been adopted.

Summary Simulation platforms have been developed for technical and non-technical surgical skills, educational bootcamps, and tools for evaluation and feedback. While trainees find the opportunity to practice their skills beneficial, there may be difficulty with access due to cost and availability. Additionally, there is a need for more objective metrics demonstrating improvement in skill or patient outcome.

Keywords Simulation · Virtual reality · Surgical skills training · Surgical education · Educational apps

Introduction

Residency training has changed dramatically over the past several decades. The classic Halsteadian paradigm for education has evolved from achieving proficiency by hands-on experience in the operating room to an emphasis on simulation prior to independent patient contact. This method provides a safe learning environment in an attempt to minimize potential errors. In this current era of education, simulation has been rapidly integrated within medical training programs and continues to mature. Urology is a surgical subspecialty that integrates a variety of technologies into surgical practice. This often requires years of training to become proficient, even for the general urologist. In recent years, with the emergence of restricted work hours and the current healthcare environmental demands, residents have been urged further to utilize simulation in order to develop and enhance their technical skills. In this article, we provide an update on the most recent simulation tools and educational technologies for contemporary urologic trainees.

Materials and Methods

A broad-based literature search was conducted with the use of PubMed. Search terms included "urological simulation," "augmented reality," "virtual reality," "surgical education," "robot," and "surgical skills training." Articles included were published during the past 5 years (January 2014–March 2019). All studies were independently reviewed for new approaches to simulation education in the field of urology when compared with prior research.

Robotic Simulation Tools

The application and use of robotic surgery has amplified in popularity in recent years, and to match the demand, several simulators have been developed to aid with the improvement of robotic skills. Currently, there are six simulation platforms for skill acquisition in robotic training as seen in detail in Table 1 (da Vinci Skills Simulator [dVSS], dV Trainer [dVT], ProMIS Simulator, SimSurgery Educational Platform

Table 1 Robotic surgical simulators (adapted from MacCraith et al. [1••])

Robotic simulator	Origin	Year established	Cost (US dollars)	Stand alone	Haptic feedback	Full simulated procedures
dV Trainer (dVT)	Mimic Technologies (Seattle, WA, USA)	2007	$158,000	Yes	Yes	No
da Vinci Skills Simulator (dVSS)	Intuitive Surgical, Inc. (Sunnyvale, CA, USA)	2011	$89,000	No	No	Yes
RobotiX Mentor (RM)	3D Systems (Littleton, CO, USA)	2016	$137,000	Yes	No	Yes
Robotic Surgery Simulator (RoSS)	Simulated Surgical Systems LLC (San Jose, CA, USA)	2010	$120,000	Yes	No	Yes
SimSurgery Education Platform (SEP)	SimSurgery (Oslo, Norway)	2005	$62,000	Yes	No	No
ProMIS Simulator	Haptica (Ireland)	2003	$35,000	No	No	No

[SEP], Robotic Surgery Simulator [RoSS], and The RobotiX Mentor [RM]). All systems have been validated to varying degrees for educational purposes. Face validity measures how well the training platform simulates the real world. Content validity assesses how well the content is measured by the exercise. If a simulator demonstrates the ability to differentiate between levels of expertise then it is said to have construct validity [1•].

The dVSS simulator is a software package which is integrated into the da Vinci console and can also be utilized during live surgical procedures. This simulator has demonstrated face, content, and construct validity in prior studies [2••]. This is one of the more versatile platforms available as full procedures may be simulated as well as other fundamental skills such as camera movement and suturing [2••]. When comparing the most commonly used simulators in the USA head-to-head (dVT, dVSS, and RM), the dVSS has a more superior performance in face and construct validity than the other two systems. This platform is the least expensive option, costing around $80,000, but is also the most frequently unavailable to the trainers due to high intraoperative use of the robotic surgical console [3]. The major limitation of this system is that it cannot be employed when the robotic system is in use for operative procedures. This places significant constraints on use of the simulation system for resident training, especially if the console is used by multiple surgical specialties in the same hospital. As a stand-alone simulator, the dVT is the most expensive model on the market, priced around $160,000. This system has demonstrated face, content, and construct validity as noted in prior studies. Most interestingly, it is the only device that offers a haptic feedback system. Each controller provides force feedback and 7 degrees of motion. A recent study was conducted randomizing trainees to either the dVT or dVSS system for a simulation curriculum [4•]. Junior residents in the dVSS group demonstrated higher performance scores when asked to perform a vesicourethral anastomosis task on a 3D printed model after training. This presents an

important step in the demonstration of skill transferability in robotics and provides a promising platform for the future establishment of a uniform curriculum for specialty training.

The ProMIS simulator provides exercises in needle handling, object manipulation, suturing, and tissue handling/clipping, but is somewhat limited when compared with other simulators with regard to simulation curriculum and procedure-specific modules. The ProMIS system has shown face, content, and construct validity [5]. It is not considered a stand-alone simulator as it requires connection of the da Vinci robot to the ProMIS system for assessment [6].

The SEP simulator was developed in 2005 in Norway and is a stand-alone robotic/laparoscopic simulator. Two instruments with 7 degrees of movement are connected to the master console which tracks the position of the controllers in space. This tool offers exercises to develop needle handling skills, object manipulation, and suturing [2••]. It has also shown face, construct, and content validity, however lacks 3D imaging [7].

The RoSS is a stand-alone robotic simulator which is a mock-up of the dVSS console. Two handheld instruments with 6 degrees of movement are available inside of the consoles which provide 3D vision. Pedals for clutch and camera movement are also provided [8]. A wide array of exercises is offered in addition to full simulated procedures. Face and content validity has been demonstrated [2••].

Lastly, the RM is the newest stand-alone robotics simulator on the market which was released in 2016. It is another mock-up console which offers 3D vision, foot-pedals, and two controllers. This platform offers multiple exercises, and it is considered one of the broadest range simulators in addition to the dVSS and RoSS.

A recent survey of training programs throughout the USA showed that 87% of residency program directors believed that a standardized simulator curriculum needs to be established. However, the majority of those surveyed also expressed that cost is a hindrance to utilizing surgical simulators [9]. Other

limitations include a lack of haptic feedback, although there does not yet appear to be a consensus on the value of force assessment in performing minimally invasive surgery [10].

These six simulators offer a wide variety of training exercises for robotic skill acquisition. Yet, there has been a lack of comparative studies and validation standardization, as demonstrated by MacCraith et al. [2••]. A systematic review of robotic virtual reality (VR) simulators recently concluded that there is an urgent need for a large, multicenter, randomized controlled trial to assess the transferability of skills into the operating room [11•]. The ultimate goal is to provide a cost-effective and widely validated simulator which can be utilized in a formalized robotics curriculum.

Laparoscopic Trainers

The benefits of laparoscopy/minimally invasive surgery on patient recovery have been well-established, and this operative approach will continue to be relevant in the urological world for a broad range of procedures. As such, urologic trainees should continue to develop skills in this area of practice. A Cochrane review was conducted regarding the effects of laparoscopic box trainers and it was found that all types of simulators (box, animal, and cadaveric models) appear to improve the overall skill of trainees with no prior experience [12•]. To combat high cost and improve resident access, Aslam et al. developed a homemade laparoscopic trainer using a plastic storage container and a mounted webcam [13]. When compared with commercial laparoscopic simulators, it was widely accepted among participants, and there was no difference in performance on tasks such as circle cutting, peg transfer, and knot tying. Additionally, in an effort to improve the impact of VR simulators, Makiyama et al. developed a trainer which enables the surgeon to practice patient-specific procedures such as nephrectomy, partial nephrectomy, and pyeloplasty using dynamic computed tomography data files which are used to create simulator modules [14]. This VR trainer has demonstrated face and content validity after evaluation by three surgeons when comparing simulations to the actual real-world, patient-specific procedure.

Endoscopic Training Tools

Upper Urinary Tract

Simulation is particularly important in upper urinary tract endoscopy due to the steep learning curve for this technique. To meet this need, Inoue et al. created the Smart Simulator with important features such as portability, respiration-induced renal movements, pyelocaliceal models, accurate ureteroscopy environment mirroring the clinical setting, and the ability to create papilla size equivalent to that of an access sheath. This demonstrated acceptable face and content validity and was shown to be superior to the Scope Trainer [15].

Percutaneous nephrolithotomy (PCNL) has been shown to be one of the most challenging endourological procedures to master, and trainees require exposure to approximately 24 surgical cases to obtain accurate proficiency [16]. Preparation for this operation is vital, and several advances have been made recently with the development of a full-immersion simulation platform by Ghazi et al. [17•] and improvements in surgical planning with full immersive virtual reality [18].

Lower Urinary Tract

A wide variety of simulation systems currently exist for surgical training for lower urinary tract procedures [19••]. The Bristol TURP trainer allows users to resect prostate tissue, identify key anatomical landmarks, and to perform fluid management in a sealed plastic chamber. Unfortunately, this model demonstrated limited realism due to the lack of bleeding [19••]. The University of Washington's TURP trainer continues to be one of the most extensively validated VR simulators currently available. Users receive a detailed performance evaluation after completing a full TURP procedure. This model has demonstrated face, content, and construct validity [20]. A photovaporization of the prostate VR simulator has also been developed which provides the user with six different surgical cases and many additional instructional exercises to aid with mastering this procedure. Aydin et al. demonstrated face, content, and construct validity, and concluded that there was a significant reduction in operating time and errors with the use of the simulator [21]. Holmium laser enucleation of the prostate has been widely considered a challenging lower urinary tract procedure with a steep learning curve. The UroSim™ HoLEP Simulator is a VR simulator which most importantly aids with anatomy visualization and provides six different operative cases for learning [22]. The Simbia TURBT (transurethral resection of bladder tumor) simulator recently established face, construct, and content validity. This is a high-fidelity trainer which allows participants to resect material from a bladder model using monopolar or bipolar energy. A real-world resectoscope is used and connected to continuous irrigation [23]. This is a valuable tool to add to the urology curriculum. Prostate biopsy simulators are also available, as Fiard et al. created a trainer which provides haptic feedback in a progressive exercise environment and allows users to perform a 12-core biopsy [24].

Open Skills

There is also a clear need for additions to available simulation tools in open urologic surgery. Rowley et al. developed low-cost and reusable trainers which can be made from common household food items such as fruit, pasta, and empty milk/juice containers [25•]. Various procedures such as wound closure, open prostatectomy, delicate tissue simulation, and knot tying were easily simulated in low-fidelity models. Residents widely felt that this was useful for training and that these could be easily recreated at home. Singal et al. developed an anatomically correct, low-cost, reusable, low-fidelity suprapubic catheter model [26]. Experts and trainees both were highly satisfied with this simulator and felt that it demonstrated significant realism.

Cadaver Labs

The study of human cadavers has been one of the most relied upon methods of anatomy knowledge attainment in the medical field since it began to be studied. These labs typically are not commonly utilized in residency training mainly due to time, cost, and availability constraints. However, this form of learning comes closer to real surgical simulation than any other platform. Researchers continue to explore this avenue with enduring results.

Lentz et al. studied the impact of a penile prosthesis placement cadaver lab on 31 residents [27]. Results demonstrated significant increases in procedural knowledge and overall surgeon confidence levels. The greatest benefit was seen in residents with the least amount of prosthetic surgical experience, which suggests that this form of teaching and surgical skill acquisition should be introduced early in the training process. This article also highlighted the potential disadvantages of cadaver use, as costs were nearly $1500 per each resident who participated.

Additionally, cadaver labs have been shown to be highly beneficial with many types of procedures. Bertolo et al. have recently demonstrated that robotic training with human cadavers is highly accepted among residents and their supervisors [28]. An immediate improvement was seen in resident performance after a one day course. The majority of residents felt that this form of training utilizing human cadavers is superior to virtual reality simulators and pig cadaver labs.

Three-Dimensional Technology and Augmented Reality

Three-dimensional technology has been increasingly utilized in medical education and surgical preparation over the past several years with the thought that it provides an increased understanding of surgical anatomy. As anatomy is the foundation of surgical success, Lin et al. recently demonstrated that junior residents achieved higher increases in performance on anatomy/imaging tests after being provided with 3D CT images as opposed to standard 2D images [29]. No significant improvement was seen in the scores of higher level residents, which suggests that this technology should be introduced early on in residency education.

Parkhomenko et al. utilized immersive virtual reality to validate improvements in surgical preoperative planning and patient education [18]. Surgeons used head-mounted Oculus Rift displays (VR headsets) prior to percutaneous nephrolithotomy procedures which allowed for them to experience and manipulate the models based upon patient-specific anatomy. This technology was shown to decrease fluoroscopy time, blood loss, and also altered the approach for surgical access in almost half of all cases studied.

Printing of 3D physical models has also been increasing throughout the field in surgical planning and simulation. Physical creation of target organs through 3D printing for surgical preparation and education has been previously validated by Porpiglia [30]. This has been demonstrated for several procedures such as: radical prostatectomy, partial nephrectomy, and percutaneous nephrolithotomy. A full task trainer for PCNL procedures was created and validated by Ghazi et al. [17•]. These models were created using 3D printed injection molds. The task trainer showed excellent face, content, and construct validity as evaluated by expert and novice surgeons.

A model of the completion of a vesicourethral anastomosis during radical prostatectomy was recently authenticated by Shee et al. [31]. This model was widely rated as superior to digital VR trainers. Content and face validity was rated highly by all participants involved.

Augmented reality (AR) is a form of technology that refers to the alignment of preoperative patient images directly onto the patient or video (laparoscopy, robotics) in real time during a surgical procedure. This is thought to benefit surgeons mostly in the identification of vital structures such as vessels, nerves, and other important anatomic landmarks as they are directly projected onto the patient using preoperative 3D CT or MRI reconstructions. AR may also be used for training purposes, in preoperative preparation, or directly in the performance of a procedure. In the future this may be particularly helpful in percutaneous stone procedures to maximize safety during placement of an access sheath [32•]. Further research is needed to validate this technology, as a recent systematic review concluded that there is limited evidence showing superior therapeutic benefits when compared with conventional surgery [33•].

Simulation Curriculums and Boot Camps

Currently, a standardized robotic curriculum has yet to be developed for use in urology trainee education. There are few

validated robotic programs with established curricula at this time. One of the most widely utilized training programs is from the European Association of Urology (EAU), which combines observation of cases with wet/dry lab experience, mentored operative experience, and video performance analysis of a robotic prostatectomy procedure [34•, 35]. The other established robotic curriculum is the British Association of Urological Surgeons program, which is largely based upon the EAU format. This utilizes online learning, simulation training, observation of procedures, a mentorship period, and concludes with a final sign off point for independent surgery [34•].

Urology boot camps for new trainees have demonstrated promising results for new skill acquisition. With endoscopic treatments being one of the core elements of urological education, Hanchanale et al. described success of a boot camp with new urology residents focused on the proper assembly of a cystoscope, resectoscope, and urethrotome [36]. Significant improvements in performance were seen on post course assessments for all endoscopic instruments included.

The Urology Simulation Boot Camp (USBC) developed in the UK and described by Kailavasan has shown promising results for young trainees [37]. Residents involved in this program undergo eight modules to aid with improvement in knowledge, technical, and non-technical skills. Pre and posttest assessments were completed, demonstrating significant improvement in participants' knowledge. Instrument identification and assembly improved significantly from baseline, in addition to the mean time to complete the laparoscopic skills assessment.

Ahmed et al. described a cadaveric simulation curriculum to benefit trainees of all stages [38]. Over a three-day period residents simulated procedures specific to their level of training (module 1 - core operative urology, module 2 - core endourology, and module 3 - emergency and trauma urology) on fresh-frozen cadavers. Trainees felt that their confidence improved as a result of their participation in this curriculum. In addition, they learned pertinent anatomy, steps of key operations, and technical skills, which were transferable to the operating room.

Non-technical Skill Development: Simulated Ward Rounds

Developing non-technical skills outside of the operating room is extremely important for patient safety. Somasundram et al. introduced residents to simulated ward rounds to aid with the development of skills to treat emergent urology-related problems [39]. Participants individually led a simulated ward round with actors as patients. Distractions were deliberately introduced requiring the residents to assess and treat a patient with a urologic problem. The utility of this course was highly rated by the majority of all participants.

Evaluation Tools and Metrics

Continued evaluation and assessment is important to gauge improvement over time. The Accreditation Council for Graduate Medical Education (ACGME) recently mandated postgraduate medical training programs across specialties to evaluate their trainees based on core competencies. Simulation assessment tools have continued to improve throughout the years, yet best practices in providing consistent and objective feedback to trainees using simulation tools remain unclear. This has been an ongoing question since the inception of surgical simulators, as many tools rely solely on expert observation. The most commonly used forms of evaluation are the Global Evaluative Assessment of Robotic Skill (GEARS) [40], Global Operative Assessment of Laparoscopic Skills (GOALS) [41], and Objective Structured Assessment of Technical Skills (OSATS) [42]. GEARS is a tool for robotic surgery which requires expert surgeon input to evaluate trainees in 6 separate skill domains. GOALS is a validated assessment tool for laparoscopic surgery which is used to evaluate depth perception, bimanual dexterity, efficiency, and tissue handing. OSATS focuses on technical proficiency in open surgery, evaluates respect for tissue, time/motion, instrument handling, and flow of operation/forward planning. All of these assessment models require direct observation by experts in the field using a 5-point Likert scale, which is subject to bias. Investigators are striving to find a common form of evaluation which is reliable, objective, and cost-effective. We will highlight many of these recent developments here in addition to novels forms of feedback.

First, many forms of video-assisted, computerized data gathering techniques have begun to emerge over the past decade and this continues to evolve and be refined in the field of urology. Handelman et al. recently developed a software algorithm to evaluate resident laparoscopic cutting performance in a box trainer simulator [43]. This video-assisted algorithm used a suspended camera in the box trainer to gather performance data. Once the task was concluded, the trainee was given a score of 0-100 which evaluated performance relative to other residents of their level. This is highly beneficial as no instructor is needed for assessment.

In an effort to move toward standardized competencies for technical proficiency in robotic surgery to aid in skill acquisition, Hung et al. focused on the use of objective surgeon performance metrics [44•]. Video synchronized objective performance data was collected using the da Vinci surgical system from both expert and novice surgeons performing robot-assisted radical prostatectomy procedures. Overall findings demonstrated that experts were more efficient in their movements, and when compared with GEARS, there were limited associations. Automated performance metrics have demonstrated accuracy in assessing surgeon expertise in evaluation of the performance of vesicourethral anastomosis during robotic-assisted radical prostatectomy [45].

Kim et al. recently demonstrated that the use of early feedback to junior residents by expert surgeons led to greater improvement in performance scores during flexible ureteroscopy simulations when compared with residents receiving feedback much later in the training process [46]. Surgical simulation continues to benefit tremendously with the aid of seasoned surgeons.

Currently, there is a lack of standardized assessment in urologic training. A taskforce was recently created by the Society of Academic Urologists in order to aid in the development of a curriculum for urology interns [47••]. PGY-2 residents were surveyed and a gap-analysis was completed. Perceived gaps in technical skill were noted among bedside procedures (cystoscopic catheter placement, priapism management, female pelvic exam) and operative procedures (cystoscopic stenting, tissue dissection, instrument identification). Gaps in logistical training included formal operating room (OR) and electronic medical record (EMR) orientations and an organized list of off-hours resources. The committee recommended implementing the American College of Surgeons phase 1 and 3 programs, in addition to utilizing formative assessments (OSATS, GEARS, CSATS), simulation skills, and critical soft-skills education focused on professionalism and communication skills.

Smartphone Applications for Educational Feedback

As duty hour restrictions are continually emphasized for trainees, directed, constructive feedback becomes exponentially more relevant in order to maximize acquisition of knowledge and surgical skill. Several mobile platforms have sought to target this area. myTIPreport is a smartphone application which allows attending surgeons to provide procedure-specific feedback to residents after the case concludes. A recent study of urology residents and attendings demonstrated that feedback was felt to be beneficial to training in 100% of trainees. Eighty-nine percent of attending surgeons believed that this platform aided with surgical skill acquisition [48]. The M3app, released by Mission3, is primarily focused on providing real-time feedback for residents and medical students linked to ACGME milestones. Currently, this is limited to primary care specialties and may be difficult to translate into surgical fields. The SIMPL app is another smartphone platform which is surgery specific and leads to timely feedback for residents. This application is based upon the "Zwisch" scale which identifies four levels of faculty guidance during a procedure (1 - show and tell, 2 - active help, 3 - passive help, and 4 - supervision only). The faculty member evaluates the resident's performance according to the scale and also takes into account the complexity of the procedure based on patient factors such as anatomy, pathology, and comorbidities.

Conclusion

Simulators are currently available for the full breadth of urologic practice with devices spanning robotic, laparoscopic, endoscopic, and open surgical procedures. The educational value for trainees of all levels is clear, but the greatest benefits are seen in early residency. Changes in the current healthcare environment necessitate prior training and simulation outside of the operating room. Trainees should be well-equipped for real-world situations with the use of these devices, but we must continue to strive to further the field of education by establishing a standardized curriculum. This field will continue to grow at a rapid pace for the foreseeable future.

Compliance with Ethical Standards

Conflict of Interest   Brandon S. Childs, Marc D. Manganiello, and Ruslan Korets each declare no potential conflicts of interest.

Human and Animal Rights and Informed Consent   This article does not contain any studies with human or animal subjects performed by any of the authors.

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