Robotic Simulation in Urologic Surgery

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ABSTRACT

Robotic surgery continues to revolutionize the field of urologic surgery, and thus it is crucial that graduating urologic surgery residents demonstrate proficiency with this technology. The large learning curve of utilizing robotic technology limits resident immediate participation in real-life robotic surgery, and skill acquisition is further challenged by variable case volume. Robotic simulation offers an invaluable opportunity for urologic trainees to cultivate strong foundational skills in a non-clinical setting, ultimately leading to both competence and operative confidence. Several different simulation technologies and robotic assessment protocols have been developed and demonstrate validity in several domains. However, despite their demonstrable utility, there is no formal robotic curricula within US urologic surgery residencies. In this article, we will review the current state of robotic simulation training in urologic surgery and highlight the importance of its widespread utilization in urologic surgery residency training programs.

KEYWORDS: simulation, robotics, urologic surgery, education

INTRODUCTION

While many surgical specialties are only now adopting the use of the da Vinci robot, urologic surgeons have become increasingly facile with this system for complex pelvic surgeries since its introduction in 2000. Today, its use continues to expand across the various urologic subspecialties. Robotic surgery has paved the way for many great advances in patient care and outcomes, especially with regards to reduced morbidity and shortened hospital stays.[1] With this widespread transition to minimally invasive technique, the importance of graduating urology residents with robotic proficiency has only become more critical. Robotic simulation is of significant interest to surgical educators for preparing urologic surgery residents for their future careers, regardless of subspecialization. However, to date there is a lack of standardized robotics training curricula within United States (US) urology residency programs. Herein, we highlight the importance of robotic urological surgery simulation, describe the basics of simulation training, and review current available simulation assessments and technologies.

BENEFITS OF SURGICAL SIMULATION

There are many essential benefits robotic simulation offers to surgical trainees. However, of utmost importance is its impact on patient safety. It is well understood that the risk of adverse events is inversely related to years of robotic experience.[2] In 2015, the Emergency Care Research Institute (ECRI) cited insufficient training in robotic surgery as one of the top ten health hazards of the year.[3] To address this risk, the authors proposed a comprehensive program, which includes initial observership, bedside assistant experience, and simulation training prior to real-life robotic surgery under the supervision of a proctor. Prior studies have demonstrated significant improvements in technical performance after training with virtual reality simulators, highlighting the vital role simulation can play in improving patient outcomes and reducing overall morbidity.[4,5,6]

The importance of robotic simulation is further underscored by the impact of the COVID-19 pandemic. Reduced case load during COVID-19 caused a significant reduction in operative case numbers for residents, leading to increased anxiety about performance.[7] One study demonstrated a reduction in perceived robotic skills amongst trainees with an associated increase in time to completion of suturing techniques.[8] Formal simulation programs have been proposed as a solution to addressing this lack of surgical exposure.[9] An obvious barrier to such a program, however, is trainee engagement, which is challenged by long work hours and varying call schedules that limit free time. One proposed solution is gamification of simulation technology, which has been shown to encourage resident participation while also providing a means for practicing and learning. Unfortunately, confidence in skills was not greatly impacted, suggesting a need for additional engagement strategies.[10]

VALIDITY

The utility of any robotic simulator relies on external validation of the system. In robotic surgical simulation, validity is defined by several different parameters. **Table 1** summarizes some of the important validity tests for robotic simulation.

Table 1. Definitions of validity terms related to virtual reality in robotic simulation

Validation Domain	Description
Face	Defines how well a simulator physically mimics real life
Content	Measures whether specific modules on a simulator represents the skills it intends to test
Construct	Measures if and how well a simulator can differentiate between an expert and novice performance
Predictive	Defines the simulator's ability to predict an individual's future performance

The first is construct validity, which assesses how well a particular task within a simulator actually represents an operative setting to the point that it can distinguish a novice from an expert surgeon. In other words, construct validity defines a system's ability to gauge competency. Similarly, content validity assesses whether a simulated task is actually representative of the skills it intends to test. Face validity is another measurement which defines how well the simulator technology physically mimics real-life surgery. Lastly, the predictive validity of the simulator defines the technology's ability to predict future performance. This domain of validity is of particular interest in simulated technology for surgical training as it may help identify a trainee's readiness to progress to higher levels of training. High-quality simulators should have demonstrable validity within several of these areas.

CURRENT SIMULATOR TECHNOLOGY

The use of simulators and virtual reality (VR) has increasingly been used in the acquisition of urologic robotic surgical skills on the da Vinci surgical system. VR training for robotic skills – rather than using the robotic system itself – may decrease cost, allow for more clinical utilization of the robotic system, and help promote validated curricula with objective performance metrics.[11] The most common VR simulators currently available on the market, including cost, developer, and release year, are summarized in **Table 2**. Other platforms include the Surgical Education Platform (SEP) and ProMIS Simulator; however, these are less frequently utilized in the US and are thus omitted from the discussion.

Table 2. VR robotic surgical simulators currently available on the market

VR Simulator	Cost	Developer	Release Year
dV-Trainer (dVT)	$110,000	Mimic Technologies, Inc.	2007
Robotic surgical simulator (RoSS)	$125,000	Simulated Surgical Systems LLC	2010
da Vinci Skills Simulator (dVSS)	$80,000	Intuitive Surgical Inc.	2011
RobotiX Mentor (RM)	$137,000	3D Systems	2014

Table 3. Validity attributes for VR simulators used in urologic surgery

VR Simulator	Validity
dVT	Face, construct, content
RoSS	Face, content
dVSS	Face, construct, content
RM	Face, construct, content

While the widespread adoption of VR simulation has been limited by the high cost of these machines, significant effort has been undertaken to evaluate and compare the efficacy of the various simulators available on the market.[12] The performance of each system is measured by its validity in various categories, which were previously described. The validity attributes of each technology are summarized in **Table 3**. The dVT simulator is a stand-alone trainer, which offers the trainee the opportunity to utilize the technology without requiring access to the da Vinci system. This technology has been shown to have face, content, and construct validity.[13] The RoSS simulator, another standalone system, was shown to predict intraoperative ability and to have face and content validity.[14,15] The dVSS simulator functions as a "backpack" to the da Vinci surgical system and cannot be used without access to the console system. However, it has been shown to result in improved surgical skills amongst novices and also to have face, content, and construct validity.[16,17] Finally, the RM simulator functions as a standalone system and also demonstrates face, construct, and content validity.[18]

Several comparative studies have been conducted for these systems. Hertz et al compared the content validity and cost-effectiveness of the dVT, dVSS, and RoSS systems.[19] Using a standardized questionnaire administered to surgical trainees, all simulators demonstrated evidence of face and content validity, with significantly higher scores for the dVSS (which is the least costly, but also frequently unavailable as it comes as an attachment to the operative robotic platform). Similarly, a meta-analysis by Schmidt et al demonstrated skill transfer and predictive validity of the dvSS and Mimic dvTrainer from three pooled studies with a total of 59 participants.[20] MacCraith et al also published a comprehensive review on robotic simulation training with a special focus on urologic surgery.[21] In their review, they determine that the simulators with the broadest range of exercises are the dvSS, RoSS and RM, which include exercises for needle handling, object manipulation, tissue handling/clipping, suturing and full surgical procedures. They also highlight the challenges of global application of this technology in training, including a current lack of standardization in delivery and implementation, and prohibitively high costs.

ROBOTIC SIMULATION IN SURGICAL ASSESSMENT

Robotic simulation provides an invaluable opportunity for objective assessment and tracking of trainee progress. To date, several different evaluation scales have been developed that can be utilized for objective review of resident and fellow robotics skills. In 2012, Global Evaluative Assessment of Robotic Skills (GEARS) was the first proposed global standardized assessment tool for robotic surgical skills.[22] Using a 5-point Likert scale to quantify performance, GEARS assesses surgeon skills in a task-independent manner pertaining to depth perception, bimanual dexterity, autonomy, efficiency, and force sensitivity, and has been demonstrated to be able to differentiate individuals across a spectrum of surgical expertise.[23] Liu et al further expanded on this with the development of the Assessment of Robotic Console Skills (ARCS) tool, which incorporates assessment in efficiency in utilization of multi-wristed instruments, energy sources, and a third arm.[24] In the initial study of ARCS, all domains except energy source usage demonstrated construct validity. Similar assessment tools include the Robotic Objective Structured Assessment of Technical Skills (R-OSATS) and the Crowd-Sourced Assessment of Technical Skills (C-SATS), and formal checklists with specific focus on suturing skills and robotic dissection techniques.[25–28] These specialized assessments are summarized in **Table 4**.

Table 4. Summary of common robotic skills assessment tools

Assessment Tool	Author	Summary
Global Evaluative Assessment of Robotic Skills (GEARS)	Sanchez et al (2016)	Global rating scale of surgeon robotic skills in depth perception, bimanual dexterity, autonomy, efficiency, and force sensitivity on 5-point Likert scale
Assessment of Robotic Console Skills (ARCS)	Liu et al (2018)	Global rating scale of surgeon skills in use of multi-wristed instruments, field of view optimization, instrument visualization, workspace efficiency, force sensitivity, and basic energy source utilization on 5-point Likert scale
Robotic Objective Structured Assessment of Technical Skills (R-OSATS)	Siddiqui et al (2014)	Assessment of robotic skills in terms of depth perception, accuracy, force and tissue handling, dexterity, and efficiency on inanimate objects in dry-lab setting.
Crowd-Sourced Assessment of Technical Skills (C-SATS)	Chen et al (2013)	Adapted from GEARS; utilizes crowd-sourcing of surgery performance ratings
Technical checklist for suturing in robotic surgery	Guni et al (2018)	Detailed checklist assessing suturing skills in terms of needle driving, knot tying, and general principles of suturing
Dissection Assessment for Robotic Technique (DART)	Vanstrum et al (2021)	Assessment of 6 domains of dissection including gesture selection and efficacy, instrument visualization and awareness, respect of tissue planes, tissue handling, tissue retraction, and efficiency on a 3-point rating scale

While these tools exist and are used to a varying degree nationally, none have been formally incorporated into the American Urological Association (AUA) urological surgery training curricula. The most widely implemented training protocol is the Morristown Protocol, which requires trainees to complete 10 different skills on the dVSS platform at specific benchmarks. The protocol demonstrates predictive validity, and thus, is an appealing tool for both resident assessment prior to live robotic surgery, and institutional robotic credentialing.[29] The current training pathway recommended by Intuitive for the da Vinci system includes a three-hour online course, a dry laboratory session, VR simulation (if available), and then two pig procedures followed by two proctored live surgeries.[30] In 2014 the EAU Robotic Curriculum was introduced as a 12-week program, including eLearning, procedure observation, didactic teaching, dry lab/VR simulation, nontechnical skills training, wet lab simulation, and modular operative training to train for robot-assisted laparoscopic prostatectomy (RALP). This was shown to be a valid and effective method to train for RALP.[31]

ROBOTIC SURGICAL GESTURES

Recently, there has been a growing interest in identifying correlations between specific surgeon psychomotor skills and patient clinical outcomes. Deconstruction of the surgical procedure into the smallest meaningful interactions between surgical instrument and tissue, or gestures, may further quantify surgeon skills and identify optimal procedural protocols. Dr. Andrew J. Hung and his colleagues have pioneered this work in robotic surgery. Initially, they identified 9 dissection and 4 supporting gestures as the fundamental instrument movements necessary for robotic surgery. They validated their findings through cross-referencing 40 videos of robotic hilar dissections during robotic-assisted partial nephrectomy.[32] More recently, these gestures have been utilized to predict patient-related outcomes and to classify specific movements based on quality and efficacy. This exciting work provides a novel perspective on surgical assessment and may pave the way for identifying best surgical practices to help guide future surgical robotic training.[33,34]

SYNTHETIC SURGICAL MODELS

Finally, other emerging technologies, including synthetic organs and models, are increasingly being utilized for robotic surgical training. As the technology of these synthetic models increases, they are slowly replacing the typical animal and cadaveric models that have been used for advanced robotic surgical simulation since its inception. These synthetic models present not only a more reliable, cost-effective option compared to cadavers, they also negate ethical concerns related to use of animals in surgery. The clinical applications of 3D-printed models for robotic simulation in urology have been previously reviewed and their development continues to expand.[35,36] Most notably, the Simulation Innovation Laboratory at the University of Rochester led by Dr. Ahmed Ghazi has developed and validated realistic simulation models for robot-assisted kidney transplant, robot-assisted partial nephrectomy, and RALP.[37–39] Other models have been developed for percutaneous nephrolithotomy (PCNL), partial nephrectomy, transurethral prostate resection (TURP), RALP, pyeloplasty, and kidney transplant. An attractive aspect of these models is their consistency and reliability in the educational setting. Thus, as the technology continues to become more sophisticated, increased utilization of these simulation models in surgical training is likely to become more apparent.

CONCLUSION

Robotic surgery has become a hallmark of urologic surgery and now plays a significant role in many subspecialties including pediatrics, intraabdominal reconstruction, female and pelvic floor reconstruction, and urologic oncology. Robotic surgery has optimized patient postoperative outcomes for many common urologic surgeries, and its utilization is likely to continue to expand. Therefore, it is imperative that urologic surgery residents are well-trained in the utilization of this technology. While many virtual reality technologies and high-fidelity anatomic models have been developed to train urologic surgery residents in robotics, the lack of a formalized curriculum results in variable exposure in each training program. Nonetheless, it is clear that the available robotic simulation technology offers a unique opportunity for skill acquisition while preserving patient outcomes, and its formal incorporation into residency training is essential. These technologies are likely to continue to develop in the coming years, and their validity and applicability must be redemonstrated with each iteration. The utilization of synthetic models provides further standardization of surgical simulation and represents an exciting new field for growth. Therefore, as robotics continues to redefine urologic surgical technique and patient outcomes, the evolution of our field has never been more exciting.

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Disclosures

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