Current status of robotic simulators in acquisition of robotic surgical skills

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Purpose of review
This article provides an overview of the current status of simulator systems in robotic surgery training curriculum, focusing on available simulators for training, their comparison, new technologies introduced in simulation focusing on concepts of training along with existing challenges and future perspectives of simulator training in robotic surgery.

Recent findings
The different virtual reality simulators available in the market like dVSS, dVT, RoSS, ProMIS and SEP have shown face, content and construct validity in robotic skills training for novices outside the operating room. Recently, augmented reality simulators like HoST, Maestro AR and RobotiX Mentor have been introduced in robotic training providing a more realistic operating environment, emphasizing more on procedure-specific robotic training . Further, the Xperience Team Trainer, which provides training to console surgeon and bed-side assistant simultaneously, has been recently introduced to emphasize the importance of teamwork and proper coordination.

Summary
Simulator training holds an important place in current robotic training curriculum of future robotic surgeons. There is a need for more procedure-specific augmented reality simulator training, utilizing advancements in computing and graphical capabilities for new innovations in simulator technology. Further studies are required to establish its cost–benefit ratio along with concurrent and predictive validity.

Keywords
robotics surgery, simulation, surgical training, virtual reality

INTRODUCTION

The use of the robotic platform in urology has expanded exponentially over the last decade and has established itself in most advanced centres across the world, particularly in the USA [1–3]. In 2013, approximately 80% of radical prostatectomies were performed using robotic platform in the USA [1]. This tremendous growth in robotic technology has highlighted the increasing demand for surgeons trained in robotic skills. Although most urology residency programs are presently incorporating robotic surgery as a part of their curriculum, adequate training of these future robotic surgeons is facing many challenges [4–6]. First, there has been a decrease in actual training hours along with risk of litigation, increased emphasis on patient safety and improved surgical outcomes. Second, the traditional Halstedian method of training of 'see one, do one and teach one' does not apply to robotic technology. The robot-assisted radical prostatectomy is a complex procedure requiring complete knowledge of pelvic anatomy and an understanding of magnification, depth perception, three-dimensional spatial orientation and coordinated hand–eye movements. Third, in robotics, the mentor is not working close to the trainee with one person at the console and one other person required for bedside assistance, thus raising concerns in the mentor's mind about the patient's safety [7–9]. The training can be divided as preclinical and clinical [4–6]. The preclinical training includes use of simulators, defined as tools

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KEY POINTS

- The simulator training can form an integral part of credentialing and training robotic surgery of future robotic surgeons.
- It has the potential to decrease the learning curve for the acquisition of robotic skills.
- It can supplement the hands-on training clinical phase and can act as a bridge between preclinical training and actual hands-on clinical training without jeopardizing the safety of patients.
- There is a need for more procedure-specific augmented reality simulator training in a cost-effective manner, with more emphasis on both technical skills and team-work training.

enabling the operator to reproduce or represent under test conditions a phenomenon likely to occur in actual performance. Clinical training includes observation, bed-side assistance and hands-on-training under mentorship (including Tele-mentoring) and proctoring [4,7,10].

Simulators can be classified as low fidelity, high fidelity, virtual reality and augmented reality [4–7,11,12■■]. Low fidelity simulators, like Dry lab laparoscopic box trainer, are portable, less expensive and have been proven to improve surgical skills over time. But, they have disadvantages of lack of duplication of a real surgical environment, lack of feedback and inability to teach an entire procedure. High fidelity simulators include animal models, cadavers and commercially available models. They have advantages of providing a more realistic environment for training, but also have disadvantages such as lack of easy availability, cost, ethical issues, veterinary assistance, anatomical variance from human organs (with animal models) and lack of bleeding and actual tissue compliance (for cadavers). The Virtual Reality simulator utilizes a computer-derived realistic virtual operative field with tactile feedback on laparoscopic instruments. The Augmented Reality simulator provides a more realistic procedure-specific operating environment, where events on the field are enhanced and supplemented [12■■,13,14].

Simulators enable residents and novice robotic surgeons to practice their skills in a nonclinical environment, any number of times, without risking the actual patients. Moreover, they provide trainees a platform to assess their performance and keep track of progress over time. Additionally, they provide an opportunity to a surgeon to refamiliarize himself with the surgical console immediately before a case as a 'warm-up' before surgery [4–10].

The simulator training can be further classified into two types – skills training and procedure-based training [4–6]. Most of the virtual reality simulators provide skills training including cutting, depth perception, hand–eye coordination, suturing and retraction. Recently, procedure-based training simulators have been reported, which can act as a bridge between formal and informal training [13,14,15■■].

In this systematic review, we have reviewed all publications in PubMed in the last 12 months using keywords: simulation, robotic training, virtual reality, augmented reality. We will discuss the current status of all existing simulators in robotic training including their advantages, disadvantages, all recently published modifications in simulators technology, assessing their place in current robotic training curriculum, along with the recent developments in simulator technology and future challenges in the simulator training for acquisition of robotic skills.

VALIDATION OF SIMULATORS

Although simulators have shown their utility over other educational tools like didactic teaching and dry lab training, they need to be validated before their effective integration into teaching and training curriculum [4–6]. Validation can be subjective and objective. The subjective validation includes face and content validity. Face validity is defined as the informal assessment of realism and feel by no experts. Content validity is defined as the formal assessment of appropriateness as a teaching tool by experts. The objective validation, which is a much more daunting task, includes construct, concurrent and predictive validity. Construct validity is defined as the ability of a simulator to discriminate experts from novices. The term 'novice' includes subjects with no experience at all in performing the procedure under study. The term 'expert' includes subjects with adequate experience in performing the procedure under study. Concurrent validity is defined as the ability to compare performance on a simulator with gold standard tests known to measure the same domain, such as a tissue or animal lab. Predictive validity is defined as the ability to predict future performance based on performance on the simulator [4–10].

VIRTUAL REALITY SIMULATORS

We found five different types of virtual reality simulators published so far in the literature.

SimSurgery Educational Platform Robot

The SimSurgery Educational Platform (SEP) Robot (SimSurgery, Oslo, Norway) is a modification of the SEP Basic laparoscopic virtual reality simulator. It replaces the simulated laparoscopic instruments with the wristed instruments found in the da Vinci robot, providing seven degrees of freedom. It does not provide three-dimensional images, fourth arm integration or performance feedback. It also does not include the following tasks: camera and clutching; needle control and driving; energy and dissection [9,16]. The experience with this simulator is not as robust as with other simulators, though it is an extremely cost-effective alternative. However, the face, content and construct validity have been proven in literature [9,16].

Robotic Surgical Simulator

The Robotic Surgical Simulator (RoSS) is another type of virtual reality simulator offering 16 modules with progressive difficulty from pinching, camera and clutch operation to tissue cutting and cautery. It is a stand-alone system mimicking da Vinci Surgical System. It helps in developing motor and cognitive skills for performing robotic surgery by providing in-vivo virtual operative steps with three levels of complexity in the form of modules for orientation, motor skills, basic surgical skills and intermediate surgical skills [17]. The face and content validity have been published for this simulator, but there is currently no literature on construct validity [4,9]. The educational impact of this simulator has been published as those trained on RoSS took less time to complete robotic dry tasks [18]

ProMIS

The ProMIS hybrid simulator (Canadian Aviation Electronics Healthcare, Canada) has a computer and a laparoscopic interface made with a plastic mannequin with a black Neoprene cover. There are three camera tracking systems to detect any instrument inside the simulator from three angles, thus recording the three-dimensional position of tips of instruments 30 times/second. It can be used for various tasks like intracorporeal suturing, precision cutting, cannulation and peg transfer, analyzing three objective parameters of time, path and smoothness [19]. The face, content and construct validity have been reported in published literature [9,19].

Mimic dV-Trainer

dV-Trainer (dVT) is a table top-sized compact system with dual-platform capability simulating both da Vinci S, Si and Xi robots. It utilizes precise modelling of robot kinematics, foot pedals and master grips. This provides trainees with a realistic representation of the da Vinci system. This provides both basic (Endowrist manipulation, camera, clutching, and troubleshooting) and advanced skills training (needle control and driving, suture and knot tying, energy and dissection) [4,7]. The face, content, construct validity and educational impact have been proven in recent published series [6,18,20–22]. Schreuder *et al.* evaluated 42 participants in three groups according to their robotic experience. Experts performed better in terms of 'time to complete' and 'economy of motion' in comparison to novices [20].

da Vinci Skills Simulator

This simulator, produced by Intuitive Surgical, can be integrated with existing da Vinci Xi or Si surgeon consoles, thus providing a practice platform to be used inside or outside the operating room, with no requirement of additional system components. This was developed in collaboration with Mimic Technologies and Simbionix and provides training modules from basic to advanced skills including Endowrist manipulation, camera and clutching, fourth arm integration, needle control and driving, energy and dissection [4,23]. The face, content and construct validity have been proven in the recent series [11,18,24–28]. Tergas *et al.* showed that training on da Vinci Skills Simulator (dVSS) resulted in significant improvement in 'time to completion' and 'economy of motion' for novices [24]. They found that autonomy of use, computerized performance feedback and ease of setup were unique advantages to dVSS, thus providing more efficient and sophisticated training in comparison to conventional dry laboratory training.

AUGMENTED REALITY SIMULATORS

These simulators provide a more realistic operating field to trainees, utilizing enhanced and supplemented events [29].

Hands-on-Surgical Training

This simulator is a mode embedded within the RoSS simulator and provides training in actual surgical cases such as radical prostatectomy, radical cystectomy, radical hysterectomy and extended lymph node dissection. It includes integrated user interaction, narrative instructions and guided movements. Hands-on-Surgical Training (HoST) was created by augmenting a real surgical procedure within a virtual reality framework utilizing audiovisual explanations and anatomically relevant illustrations of the critical steps of the procedure. The RoSS manipulators navigate the trainee through haptic-enabled cues during the procedure [13]. Chowriappa *et al.* [12▪▪] evaluated the role of augmented reality-based skills training for robot-assisted urethrovesical anastomosis in a randomized controlled trial, using HoST a technology group and a control group. They found that for 70% of participants, HoST the training experience was similar to a real surgical procedure and 75% of trainees responded that this training could improve confidence in performing a real procedure. They concluded that training with HoST in urethrovesical anastomosis improves technical skills acquisition with minimal cognitive demand.

Maestro AR

This was introduced by Mimic Technology, providing virtual instruments for interaction with anatomy in a 3D video environment. This has been designed for training novices in decision-making skills and procedure-specific skills, within the dVT simulator. The participants use virtual robotic instruments in anatomical regions collected from 3D surgical video. This simulator plans to provide training in four modules: partial nephrectomy (released May 2014), hysterectomy, prostatectomy and general surgery (to be released) by helping to identify anatomy, anticipate tissue retractions and predict regions for dissection [14]. There are no studies documenting face, content, construct, concurrent and predictive validity of this simulator, owing to its recent introduction.

RECENT DEVELOPMENTS IN CONCEPTS

Recently, more simulation models have been launched emphasizing the concept of teamwork and procedure-specific training in robotics.

Xperience Team Trainer

This simulator, available as an optional hardware complement for the dV–Trainer simulator, has been introduced to emphasize the importance of teamwork and proper coordination between console surgeon and assistant during robotic surgery. This simulator provides training simultaneously to both surgeon and bedside assistant. Thus, the bedside assistant performs basic skills exercises, promoting his psychomotor skills and rehearsal of interaction with console surgeon. It also exposes them to real-life situations in the operating room, promoting patient safety. Moreover, this team training helps in development of communication protocol in the real operating room using a well tolerated simulation environment. Moreover, it also provides proficiency-based scoring for the team and each individual [30]. However, studies regarding its face, content, construct, concurrent and predictive validity are still pending because of its recent introduction.

Tube 3 module with dV-Trainer

This simulator training emphasizes procedure-specific training, utilizing the Tube 3 module in the dVT. It helps in increasing vesicourethral anastomosis (VUA) performance, one of the most complex steps in robot-assisted radical prostatectomy. Kang *et al.* [15▪▪] recently published their experience with this module. They found that experts performed better in task time, total score, total economy of motion and number of instrument collisions in comparison with novices. Moreover, 80% of experts found this module a useful training tool to perform VUA. Thus, they reported face, content and construct validity of the Tube 3 module for practicing VUA.

RobotiX Mentor

This simulator has been introduced recently providing a realistic representation of the work space, master controllers, pedals and surgeon console of da Vinci Surgical System. It provides a 3D high-definition stereoscopic view for basic skills (robotic suturing, stapler, Fundamentals of Robotic Surgery modules) and multidisciplinary complete virtual reality procedures (vaginal cuff closure, hysterectomy modules), augmented with step-by-step video guidance and realistic representation of emergency situations and complications. The trainees are provided with performance reports with learning curve graphs utilizing simulator curricula management system [31]. However, face, content, construct, concurrent, and predictive validity of this simulator have not been proved in literature because of its recent introduction.

Table 1 shows comparison between the available simulators.

CURRENT CHALLENGES AND FUTURE PERSPECTIVES

The definitions of face, content, construct, concurrent and predictive validity need to be standardized for all simulators and future studies. Very few randomized controlled trials (RCTs) have been

Table 1. Comparison of different available simulators

	Face validity	Content validity	Construct validity	Concurrent validity	Predictive validity	Learning impact	Cross-modality correlation
SEP	Yes	Yes	Yes	No	No	No	No
RoSS	Yes	Yes	No	No	No	Yes	No
ProMIS	Yes	Yes	Yes	No	No	Yes	No
dVT	Yes	Yes	Yes	No	No	Yes	Yes
dVSS	Yes	Yes	Yes	No	No	Yes	Yes
HoST	Yes	Yes	Yes	No	No	Yes	No
Maestro AR	No	No	No	No	No	No	No
Tube-3 module	Yes	Yes	Yes	No	No	Yes	No
Xperience team trainer	No	No	No	No	No	No	No

dVSS, da Vinci Skills Simulator; dVT, dV-Trainer; HoST, Hands-on-Surgical Training; RoSS, Robotic Surgical Simulator; SEP, SimSurgery Educational Platform.

reported comparing different robotic simulators [32]. The superiority of one simulator over another has not been established so far because of a lack of these RCTs. There are no studies documenting the actual benefits of simulator training carried over to real-case performance with a surgical robot. The cost of these simulators is a significant matter of concern [4,7–9]. However, with increasing use of robotic technology and increasing competition among training devices, the future cost of these devices should come down to an affordable range. There is a need to provide more procedure-specific

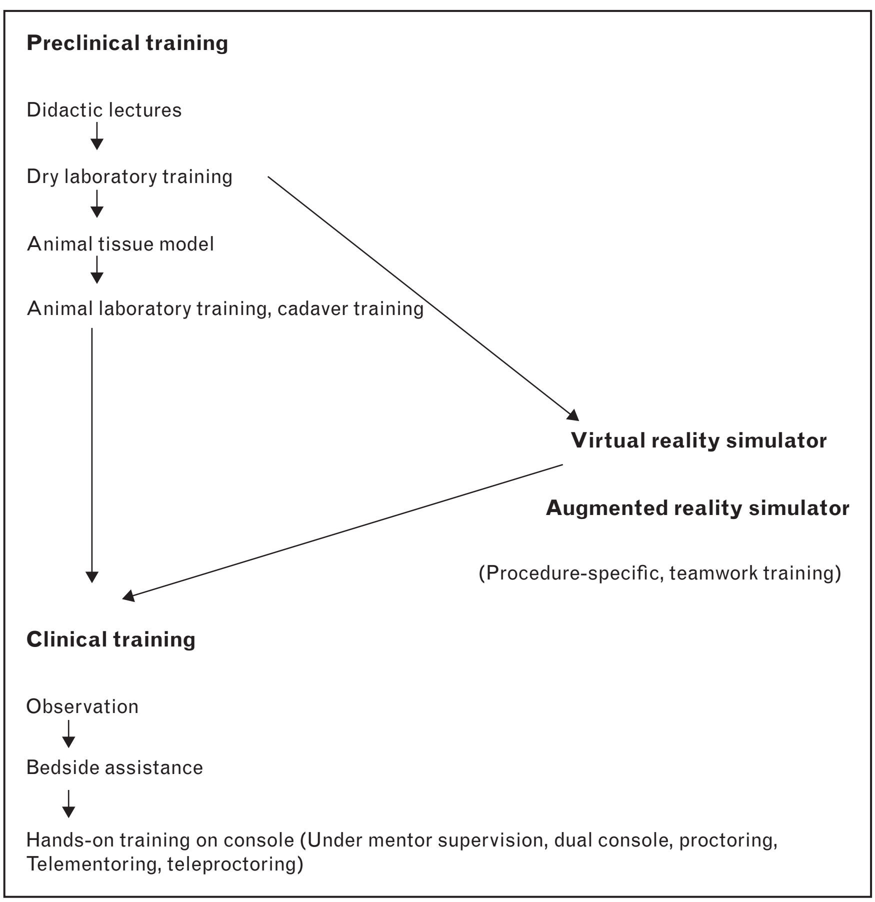

FIGURE 1. Potential role of simulators in robotics training.

training along with skills-based training in a more realistic augmented reality environment like HoST and Maestro [13,14]. Moreover, the concepts of teamworking, decision-making and communication skills should be incorporated more in simulator training by providing team-based robotic simulation environments like Xperience Team Trainer [4,7–9,30]. However, their validations have to be proved in future large prospective RCTs. Finally, there is a need for standardization for training and credentialing in robotic surgery as has been done with Fundamentals of Laparoscopy Surgery for laparoscopy in general surgery [4,7,8]. A similar standard and validated tool including simulator training and other training tools needs to be incorporated in various robotic residency and fellowship teaching curriculum (Fig. 1).

There are a few limitations of this article. First, we may have missed a few articles related to the current topic. Second, we could not discuss certain issues like cost-effectiveness, concurrent and predictive validity (tools to assess the actual benefits of simulator training carried over during real-time robotic surgery), as these issues have not been reported in published series.

CONCLUSION

The simulator training can form an integral part of credentialing and training robotic surgery of future robotic surgeons. It has the potential to decrease the learning curve for the acquisition of robotic skills. It can supplement the hands-on training clinical phase and can act as a bridge between preclinical training (didactic lectures, dry lab training, animal models) and actual hands-on clinical training without jeopardising the safety of patients. There is a need for more procedure-specific augmented reality simulator training in a cost-effective manner, utilizing advancements in computing and graphical capabilities for new innovations in simulator technology, with emphasis on both technical skills training and teamwork training. However, more RCTs involving larger numbers of participants are required to establish its cost-benefit ratio along with concurrent and predictive validity.

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