2 Robotic Simulation Training

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Introduction

Robot-assisted laparoscopic surgery continues to expand among surgical modalities in a variety of specialties [1–5]. With this expansion, it is increasingly important to provide surgical trainees with adequate training to include robot-assisted surgery in their independent practices. Additionally, just as assessment of basic laparoscopic skills has become a prerequisite of graduation from general surgical training, assessment of robotic fundamentals may also become a requirement of surgical training [6, 7]. Finally, robotics is a new and evolving dimension of surgery that holds promise to expand into nearly every surgical subspecialty and become an important modality that many fully trained surgeons will have to learn. For these reasons, developing training strategies and formalized curricula for robot-assisted surgery is a critical task for today's surgical educators.

Robot-assisted surgery represents a unique platform with many differences from standard laparoscopy and open surgery. Current robotic systems function through a communication system in which surgical tasks are performed by a platform at the patient bedside, while the surgeon exerts direct control over this platform using a console, removed from direct contact with the patient. The surgeon's console allows the surgeon to control the laparoscopic camera and to "clutch" instruments, making it possible to use their full length, while the console masters are kept at a comfortable distance from the surgeon. The surgeon may also employ more than two working arms at a time by swapping control among three engaged instruments. Additionally, different instruments can be changed out by an assistant at the patient bedside when necessary. This multifaceted construct presents many training challenges [8, 9]. The added distance between the surgeon console and robotic cart requires robotic surgery trainees, assistants, and operating room staff to gain proficiency at positioning and docking the robot to the patient ports. The added distance also requires the operating surgeon to learn to perform procedures without haptic feedback. The use of clutching, extra instruments for retraction and exposure, and camera driving by the surgeon, rather than an assistant, makes robot-assisted procedures less analogous to their laparoscopic or open counterparts. Several studies have detailed these aspects of robotic surgery, showing that laparoscopic and surgical skills are not portable across platforms and that robot-assisted surgery has a significant learning curve, even for experienced surgeons [10–14]. These findings highlight the importance of incorporating dedicated robotic training curricula, particularly simulation-based curricula, into robot-assisted surgical training.

Simulation represents an ideal strategy for robotic surgical training and is a core component of various emerging robotic training curricula [6, 7, 15, 16]. In this chapter, we will review the principles of simulation as they pertain to surgical training, the simulation models currently available, and the instruments available for assessment of training progress and competence.

Simulation

Simulation involves the modeling of a real-world process for a variety of purposes including training, education, testing and assessment, research, predictive analytics, process improvement, investigation, and entertainment. The development and study of simulation is a rapidly expanding field, particularly with the development of more powerful computer systems that can process increasingly complex simulated systems. Many of the broad uses of simulation are applicable in the healthcare setting; however, our focus is on simulation as a training, education, and assessment tool in robotic surgery. In this context, there are three classifications of simulation that form a conceptual framework for discussing specific simulated systems and training models.

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Fidelity

The fidelity of a simulation describes how accurately the simulation represents the intended reality. A low-fidelity simulation is usually a stylized or simplified depiction of a system [17]. In surgical training simulations, which are almost universally interactive, the interactions between a user and a low-fidelity simulation can still produce meaningful outputs. Low-fidelity simulations are often used to practice basic sub-tasks within a more complex process or to engage with the conceptual framework of a process rather than its practical function. High-fidelity simulations more closely mirror the process being simulated. They accurately depict a task for a trainee; therefore, as the fidelity of a task performance simulator increases, so does the ability of simulated performance to predict actual task performance.

Setting

The setting of a simulation can vary, and this is of importance when it comes to training for high-fidelity complex tasks. A live setting, in the surgical context, would be a simulation exercise that takes place in the operating room, the surgical ward, or another setting using the equipment, teams, and procedures that would be used in the real-world process. This form of simulation is commonly seen in operating room training drills, emergency response exercises, and team building programs. A laboratory simulation is one in which the simulated scenario takes place in a setting contrived for this purpose. Surgical skills labs, virtual reality environments, and animal or cadaveric operative models all represent laboratory simulations.

Computerization

Advanced computer modeling has revolutionized simulation and has led to the development of virtual reality simulators for surgical training [18]. In these simulations, a virtual environment is simulated by a computer program, and the user interacts with the virtual environment to perform the training task using various means. In contrast, physical simulations involve more traditional practical simulation models.

Models

Didactics

In discussing models of simulation for robotic surgical training, it is important to begin by discussing didactic training. While many of these didactic curricula would not necessarily be considered simulation, formal education in the concepts and theory of robotic surgery is an important foundation for further training. A variety of didactic models exist for the training of robotic surgeons. Many surgical training institutions employ an ad hoc model in which robotic surgery is mentioned in lectures or written coursework within a broader surgical training curriculum, but a robotic-specific curriculum is never taught. For fully trained surgeons who are learning robotic surgery, a similar model takes the form of informal proctoring sessions with colleagues. This lack of structured robotic training at multiple training levels combined with the increased importance of robotic surgery has spurred the development of formal robotic didactic curricula. Intuitive Surgical, Inc., has developed a set of training modules that are accessible online and cover theoretical and technical topics related to robotic surgery [19]. This online program forms the didactic core of robotic surgery curricula at several training institutions. In recent years, several textbooks and atlases of robotic surgery have been published that may be incorporated into the reading lists of residencies and fellowships.

Practical Simulation

Simulations in a practical environment include all real-world or laboratory simulations that do not involve virtual reality, which make up a large proportion of robotic training. The advantages of these simulations are that they can be very high-fidelity, can involve entire care teams instead of one individual learner, and can avoid the need to purchase dedicated simulation equipment. Additionally, the Society of American Gastrointestinal and Endoscopic Surgeons (SAGES) has published a consensus document on robotic surgery which included recommended guidelines for credentialing surgeons to perform robot-assisted surgery. For attending surgeons who were not formally trained in robotic surgery, the consensus group recommended hands-on experience in a dry lab environment as a necessity prior to embarking on actual surgery using a surgical robot [20].

One of the critical aspects of this form of simulation is in the room and robot setup. Robotic surgical cases require a precise sequence of actions to appropriately prepare the robotic platform prior to the case. This sequence includes how to drape the robot, position the patient appropriately for robotic surgery, and dock the robot to the patient once surgery has been initiated. These actions differ from the typical workflow of a laparoscopic or open surgical case and can often lead to a significant time expenditure in the operating room, which has been shown to reliably diminish as surgeons progress along the robotic surgery learning curve. Often, robotic training entails a hands-on simulated setup in a simulation lab with a robotic surgery platform or in an actual robotic operating room at a time when the room is not in use. The learner is coached in the basics of preparation for robotic surgery, including draping the robot, maneuvering the arms into place, docking, and swapping instruments. A similar, more complex form of simulation is team-based simulation focused on communication and problem-solving within a team during robotic surgery [21].

Basic console use is another area of robotic surgery often taught in a lab environment using a dedicated training robot or a robotic platform in the OR during a time when it is not in use. In addition, introductory-level robotic training courses are available around the country for surgeons at the senior trainee and attending levels to become familiar with robotic technology. In this environment, the learner is proctored in basic console use including console setup, camera control, and clutching.

Low-fidelity dry lab simulations have long been a mainstay of training in open and laparoscopic surgery and in recent years have been widely adapted for use with robotic platforms. Simple suturing and knot-tying boards, made from a variety of materials, are used by learners to practice basic operative skills outside of the operating room [22]. These tools are widely used in medical student and intern "boot camp" programs to teach fundamental skills prior to clinical immersion. Suture boards, including several robot-specific variants, have been used to similarly practice basic operative skills such as tissue handling, suturing, and knot tying, during robot-assisted surgery. A very broad array of box-based simulators have been developed for laparoscopic surgery. These constructs are based on a system in which a camera and laparoscopic instruments are introduced into a box, simulating a body cavity, to perform a task within. The tasks performed are generally low-fidelity simulations of common surgical actions like tissue manipulation, dissection, targeting and grasping objects, and intracorporeal suturing. The most important of these simulations are the required tasks in the Fundamentals of Laparoscopic Surgery (FLS) program developed by SAGES and the American College of Surgeons (ACS) [23]. This program also includes a didactic curriculum focused on laparoscopic surgery, and general surgery residents are required to pass a written exam and a skills assessment based on the FLS tasks to take the American Board of Surgery (ABS) qualifying exam for certification. Therefore, the FLS tasks and performance goals are almost universally known in surgical training programs nationwide and have been very extensively validated in a broad evidence-based research studies [23–27]. With the advent of robotic surgery, most FLS tasks were found to be easily adaptable to the robotic platform and were found to be similarly useful in developing and assessing surgical skills on the robotic platform. FLS-based tasks were used as a task performance model in many early studies on robotic surgical skills acquisition, ergonomics, and performance evaluation [23, 28–30]. They remain an important educational tool for robotic surgeons around the country. Additionally, the Fundamentals of Robotic Surgery (FRS) program, an educational project funded by the Department of Defense and Intuitive Surgical, Inc., was modeled on FLS and has developed a didactic curriculum, written examination, and trainer box-based performance assessment for proficiency certification in robotic surgery. An analogous virtual reality-based robotic surgery proficiency examination has also been developed, and validation studies comparing the two assessments are currently underway [7].

High-fidelity *in vivo*, explant, and cadaveric models are important simulation models for robotic surgery. These models allow a surgeon to practice live surgery on an animal model or use a cadaver or ex vivo model to perform surgery on true-to-life human anatomy. A simulation lab must be equipped not only with a robotic surgical platform but also with the capability to safely perform animal or cadaveric procedures for this form of simulation, making it a complex and expensive model. It is, however, the highest fidelity form of simulation for the manipulation of tissue, the interaction between the robotic platform and physical specimen, and the considerations related to operating within a living model. A large body of literature supports the use of animal and cadaveric models for robotic surgical simulation. These models are particularly useful in the development and propagation of new techniques and in expanding the indications of the robotic platform to surgical specialties and procedures where it previously had not been used [15, 26, 31, 32].

Virtual Reality Simulation

The use of virtual reality (VR) in surgical simulation represents a leap forward in simulation technology. VR holds promise for profound future advances as the technology continues to develop. Strictly speaking, VR refers to any computer-generated environment that is designed to give the user the sensation of being present within the environment rather than observing the environment. Current VR technology is usually based on a headset which projects binocular video to generate a three-dimensional image, utilizes headphones or speakers to produce three-dimensional sound, and incorporates gyroscopes and other motion sensors to track the motion of the headset to generate corresponding sensory inputs. In this way the user is immersed in the virtual setting through the sound and visual senses. Since VR has found its broadest application in video gaming, these systems often include handpieces or controllers that allow for interaction with the virtual environment. This basic construct theoretically allows interaction with any virtual environment and could be used to simulate open surgery, laparoscopic surgery, robotic surgery, or endoscopic surgery. It could also be used to simulate real surgical procedures under various conditions in living patients or clinical interactions outside of the operating room. In addition, VR systems allow for tracking of a variety of parameters that are very difficult to track in practical simulation models, such as economy of motion and simulated tension on tissues [33–35]. Finally, VR technology has the potential for allowing unique interactions between educators and learners [15, 28, 31]. For example, VR systems can allow a learner to visualize and emulate the exact actions of an expert performing a task. VR also allows for the possibility of telementoring, in which a remote expert can interact with and direct a learner or a group of learners within a virtual environment.

The potential of VR technology for surgical training and research is enormous, but currently its use is held back by the limits of graphics processing, haptic technology, and artificial intelligence. Robotic surgery, however, represents an ideal use for VR simulation. Current robotic VR simulators employ a console very similar to actual robotic surgery consoles, with computer-generated images projected into its eyepieces. The user can interact with objects in the VR environment using console handpieces just as they would during live robotic surgery. Since robotic surgical systems do not provide the user with haptic feedback from the surgical field, the VR system does not have to simulate haptics, eliminating one of the major hurdles in true-to-life surgical simulation. Additionally, the VR environment is projected into a console rather than a free-floating headset, eliminating the disorientation and vertigo that can be associated with VR environments. However, given the computational limit of modern computers, a high-fidelity simulation of complex surgical operations is not yet available on robotic VR platforms. Instead, the most commonly used VR simulators are equipped with training modules that simulate basic surgical tasks such as camera driving, targeting and transferring objects, pattern cutting, suturing and knot tying, basic use of surgical energy, and tissue manipulation [6, 33]. Metrics are collected via modules that are graded by difficulty, task completion time, motion parameters, and various faults, with a defined performance goal set for passing the module. This metrics collection feature allows learners to track their own performance and educators to design curricula using a set of modules that learners must complete to achieve basic proficiency. Several such curricula have been proposed, and several groups are currently at work validating VR-based curricula for robotic surgery and associating their use with surgeon and patient outcomes [6, 16, 34, 36].

Assessment

Most uses of surgical simulation involve assessment tools to determine utility of the simulation and evaluate the progression of users during the simulation. Two broad categories of learner assessment with wide application in surgical simulation are subjective and objective assessments.

Subjective Assessment

Subjective assessments are those that depend on the perspective of the user interacting with the simulation. These assessment tools are important for understanding how individuals perceive their interactions within a simulation and are useful for designing and improving simulated constructs. Subjective assessment tools can be simple surveys specific to a particular simulation, which provide focused and relevant data but are often not generalizable. Other subjective assessment tools are designed and validated for broad applicability to almost any task, such as the NASA task load index (NTLX), a survey instrument that assesses various domains of workload during task performance [16, 21, 23].

Objective Assessment

A variety of objective evaluations on user performance have been applied to robotic simulation. The most important of these is the performance evaluation necessary to achieve certification in the Fundamentals of Robotic Surgery (FRS) program. Objective evaluation of learners by mentoring surgeons is also necessary, and several tools have been developed for this purpose. Our group developed a robot-specific adaptation of the Ottawa Surgical Competency Operating Room Evaluation (RO-SCORE), and several other similar evaluation tools have been reported in the literature [16, 37–41]. VR simulators also provide a variety of metrics on performance time, motion, and task quality. These objective measures of task performance can be interpreted to track performance and identify specific parameters for improvement. Finally, our group and others have used objective ergonomic measures, as quantified by surface electromyography (sEMG), to quantify physical stress during task performance on simulated tasks and live operative procedures [23, 42, 43].

Conclusion

Surgical simulation tools are increasingly important in training, research, and skills assessment. They hold particular importance in robotic surgery, where simulation is central to educational curricula, skills assessment, and certification criteria. As VR technology continues to progress, it promises to revolutionize surgical simulation even further. Future research into robotic surgical simulation will be necessary to describe the effects of advanced simulation models and curricula on patient and surgeon outcomes.

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