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Learning Tools and Simulation in Robotic Surgery: State of the Art

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Abstract Robotic surgery has emerged as a new technology over the last decade and has brought with it new challenges, particularly in terms of teaching and training. To overcome these challenges, robotic courses, virtual simulation, and dual consoles have been successfully introduced. In fact, there are several simulators currently on the market that have proven to be a valid option for training, especially for the novice trainee. Robotic courses have also found success around the world, allowing participants to implement robotic programs at their institution, typically with the help of a proctor. More recently, the dual console has enabled two surgeons to be operating at the same time. Having one experienced surgeon and one trainee each at his or her own console has made it an obvious choice for training. Although these methods have been successfully introduced, the data remain relatively scarce concerning their role in training. The aim of this article was to review the various methods and tools involved in the training of surgeons in robotic surgery.

Introduction

Beginning in early 2000, robotic surgery has been emerging as a valid option for minimally invasive surgery in almost every surgical specialty. Interest has grown rapidly, and the experience has led to increased success [1], particularly for advanced and complex procedures [2–6]. Although the new generation of surgeons will grow into this technologic evolution, there are new challenges emerging with regard to the training and education of current residents and fellows. For the first time, the question of training and teaching is not only a problem of person or personality but also of machine and device [7].

It seems logical that to keep up with emerging technology residents should undergo robotic training. Yet at the same time they are required to continue their training in basic open surgery and laparoscopy skills. With already limited hours available, such training programs need to be reexamined [8]. The reality is that simulators, dual consoles, and robotic courses should play an important role in bridging the gap between early surgical skills and effective performance using the robot in a clinical setting without subjecting patients to unnecessary risk. It is also important to have tools that provide an objective means by which to evaluate a trainee's performance in anticipation of their ultimate graduation [9].

As reported by others [10], robotic training poses several unique challenges not only to trainees but to the proctors. To overcome these challenges, robotic courses and simulation have been advised [7], with the robotic system ideal for integrating various forms of simulation [11]. The use of simulators has been well established for laparoscopy [12–17], but their effectiveness for robotic surgery is not as clear. Most of the data available have to do primarily with urology [8–10, 18–34]. Thus, robotic training by simulator for general surgery remains under-investigated [35].

In this review, we aimed to identify the different simulators available on the market and evaluate their performance. In addition, we reviewed and assessed the various learning tools available to the robotic trainee, including the dual console, robotic courses, and proctoring.

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Simulators

To assess the role of simulators, it is important to define some key terms [9, 10, 36–38]. *Feasibility* refers to the measure of whether an assessment process is capable of being performed. *Validity* identifies whether an examination or test is successful in testing the competencies that it is designed to test. There are several types of validity.

- Face validity—the extent to which the examination looks like it would with the real examination (e.g., realistic)
- Content validity—the extent to which the intended content domain is being measured by the assessment exercise (e.g., usefulness)
- Construct validity—the extent to which a test measures the trait that it purports to measure (e.g., discrimination between various level of expertise)
- Concurrent validity—the extent to which the results of the test correlate with the gold standard tests known to measure the same domain
- Predictive validity—the extent to which an assessment predicts future performance

Reliability is a measure of the reproducibility or consistency of performance. Finally, *acceptability* represents the extent to which subjects involved in the assessment accept an assessment tool.

For this review, only simulators that were available on the market for robotic surgery were reviewed and analyzed.

MIMIC dV-trainer

Since 2008, several published studies have evaluated the role of the Mimic dV-Trainer (MdVT) (Mimic Technologies, Seattle, WA, USA). The MdVT is a small, tabletop-sized, stand-alone simulator that replicates the da Vinci robot. One of the first reports on the simulator was a randomized, blinded pilot study [28]. After enrollees performed robotic tasks using both the daVinci robot and the offline MdVT, 93 % thought that a simulator would be a useful training tool. Even more interesting, the majority of these learners believed that the offline trainer could teach robotic skills in a comparable manner to a dry laboratory robotic skills station. The offline trainer was able to discriminate between experts and novices of robotic surgery. Thus, the criteria for face, content, and construct validities were met in this study.

In 2009, Sethi et al. [34] evaluated 15 novices and 5 experts using the MdVT robotic simulator. They found that the MdVT allowed realistic (face validity) use and, at least for one exercise, also met the criteria for the content and construct validities.

Over the next few years, several studies evaluated the validity parameters regarding the use of the MdVT simulator [24, 26, 35, 39]. With regard to construct validity, experienced robotic surgeons typically outperformed novice surgeons in nearly all the variables, including total score, total task time, total instrument motion, and number of instrument collisions [24, 26, 29]. For face validity, the MdVT was found, at a minimum, to be "somewhat realistic" [26, 29, 35].

In terms of training, the MdVT and the da Vinci surgical system (dry laboratory) were each shown to improve robotic surgical aptitude significantly when compared to no training at all [27, 40]. Studies also found that the MdVT was equivalent to the da Vinci system for improving robotic aptitude [30], particularly in the use of Endowrist manipulation and camera movement [27]. The performance analysis software and metrics (MScore) were also independently validated [9]. Perrenot et al. [35] reported that the MdVT skills assessment can replace an expert's assessment in a robotic surgery dry laboratory. Of note, they found that the most relevant exercises were "Pick and Place" and "Ring and Rail" [35].

Finally, some modules did not exceed the acceptability threshold, including the needle-driving module [24, 26] and the needle-control module [26]. It is also important to note that the MdVT does not use the da Vinci surgeon interface. Because a significant portion of robotic skills acquisition deals with efficient use of the surgeon console and its various functions, a simulator that incorporates the actual console would theoretically be a better training tool [23].

The MdVT can help bridge the gap between the safe acquisition of surgical skills and effective performance during live robot-assisted surgery [30, 34], although the problem of the robotic suturing domain still requires further validation and improvement. In the final analysis, experienced robotic surgeons ranked the simulator as useful for training and agreed to incorporate the MdVT into a residency curriculum [24].

da Vinci skills simulator

The da Vinci Skills Simulator is the first virtual reality simulator produced by Intuitive Surgical (Sunnyvale, CA, USA) for da Vinci robotic surgery that is integrated with the da Vinci Si console. It integrates the Mimic virtual reality tasks using the da Vinci surgeon console as the user interface.

Hung et al. [23] reported that 63 participants rated the virtual reality and console experience as "very realistic." In addition, 15 expert surgeons rated the simulator as a "very useful" training tool for residents and fellows, although less so for experienced robotic surgeons. With regard to construct validity, experts outperformed intermediates and novices in almost all parameters, including overall score, economy of motion, time with excessive instrument force, instrument collisions, instruments out of vision, master controller range, missed target, time to completion, and misapplied energy. These results have been confirmed by other reports [8, 19, 31]. More interestingly, Hung et al. found that simulator training appears to be the most substantial training for trainees with low baseline robotic skills [22]. They also documented the concurrent and predictive validities of the da Vinci skill simulator.

It should be noted that other simulators directly integrated to the robotic console do exist but are still in the early pilot stages [41].

Robotic surgical simulator

The robotic surgical simulator (RoSS) system (Simulated Surgical Systems, Williamsville, NY, USA) was reported as being realistically close to the da Vinci console for virtual simulation and instrumentation [32], making it acceptable for face and content validity [42]. Additionally, this system was considered to be an appropriate training and testing module before a clinical robotic experience for residents and, as a result, can be used for obtaining privileges or certification in robotic surgery [33]. Also interesting is the fact that training with the RoSS system can reduce the time taken to complete tasks such as ball drop and needle capping on the da Vinci console when compared to participants with no training [25]. Guru et al. found that the simulator can help improve recognition of procedure-specific anatomic landmarks during surgery when using the da Vinci system [21].

In the near future, several specific modules (prostatectomy, cystectomy, partial nephrectomy, hysterectomy) should be integrated into the system, as with the MdVT (part of a prostatectomy) [43]. This addition will allow the trainee who is performing the procedure in real time to mimic the surgeon's every movement and to have the performance evaluated and measured by the system [9]. This advance could also help increase acceptance of the system.

SimSurgery educational platform robot

The SEP-Robot (SimSurgery, Oslo, Norway) is another virtual robotic simulator. It has a console connected to two instruments with seven degrees of freedom. Unlike the robotic system, however, the SEP-Robot does not provide three-dimensional images.

The experience with the SEP-Robot is more limited [20, 44–46] than that of the systems previously described. Although several groups have proven the face, content [20], and construct validity [20, 45, 46] of the system as a virtual reality simulator for robotic surgery, others have failed to confirm these results. In fact, van der Meijden et al. [44] reported that the face and construct validity still need to be improved before implementation of the SEP-Robot in its current state.

Dual console

Introduction of the da Vinci Si system has given surgeons a second robotic console, facilitating collaboration between proctor and trainee. The mentoring console has two collaborative modes [11, 47]: (1) The swap mode allows the mentor and trainee to operate simultaneously and actively swap control of the robotic arms. (2) The nudge mode allows them to have control simultaneously, sharing the two robotic arms.

Hanly et al. [47] reported that the swap mode was most useful during parts of the surgical procedures that required multiple hands (e.g., isolation and division of vessels). The nudge mode, however, was more useful for guiding resident's hands during the more crucial and precise steps of an operation (e.g., suturing). Marengo et al. [48] reported their preliminary experience with the double console, concluding that the system appeared to be a promising tool in surgical education, even for experienced laparoscopy surgeons. They also thought that introduction of the dual console could shorten the learning curve and help trainees feel more comfortable with the various procedures [48]. In fact, Smith et al. [49] used the dual console for training gynecologic fellows. Globally, the incorporation of fellow education using a robotic dual console did not adversely affect outcomes when compared to standard laparoscopy.

In conclusion, the dual console system seems promising, although it remains relatively expensive. Currently, few data are available that have confirmed the role of the double console in training, although interest in it will likely grow in the future.

Robotic courses

Training courses on robotic surgery are typically performed using inanimate, animal, or cadaver models. The length of the course varies from several hours to several days, sometimes even weeks in a mini-fellowship situation. The content depends on the population. The initiation of such a course should be proposed to a robotic "team" [50, 51], with the focus on decreasing the initial learning curve [52]. Of note, this type of training requires a robotic system that can either be reserved solely for teaching or, if it is the only clinical system on site, available for use outside of working hours [11].

Participants are typically evaluated on several factors, including time (setup, operating), the Objective Structured Assessment of Technical Skills (OSATS) score, motion analysis, complications, and errors [11, 53–61]. Several groups have reported their experience with training courses although as mentioned by Schreuder et al. [11] only a few courses included exercises to demonstrate construct validity [55, 61, 62]. Still, contrary to virtual simulation, training courses in a laboratory setting allow the participant to become familiar with the robotic system itself, including the draping, setup, and docking. Even more importantly, the participant can be trained to deal with basic troubleshooting, which can often happen during the initial experience.

Arain et al. [63] demonstrated a comprehensive inanimate training program for robotic surgery. The program resulted in significantly improved performance and showed a clear educational benefit. In addition, construct and content validity and feasibility were demonstrated [64–69]. Other groups have reported their training approach for robotic surgery, which include incorporating a knowledge module, a skill module (inanimate, animal, or cadaver models), and bedside and/or observational cases. A stepwise approach is widely recommended [70–74], as is currently performed in our institution [75].

Recently, we reported our experience [76] with a robotic course for general surgeons ($n = 101$). After a mean follow-up of 30.1 months, 46 % of participants were performing robotic procedures. More interestingly, 100 % of participants who started a robotic program at their institution following the training already had an available robot on site. While this may seem obvious, it should be emphasized because it is not clear how many institutions would have acquired the robot as a result of the participants' training and subsequent endorsement.

Others have also reported encouraging results following dedicated robotic courses [77, 78]. Gamboa et al. [79] found that an intensive 5-day course that had focused on robotic prostatectomy enabled the majority of the participants to incorporate and maintain this procedure successfully in clinical practice in both the short and long term.

Live case training and proctorships

Live case observation remains an important component of a robotic training program [11] and allows the trainee to become familiar with the steps of a specific robotic procedure. *Proctoring* is defined as direct supervision by an expert during the initial phase of training and the learning curve [11]. It provides a safe environment during the introduction of a new technique and prevents surgeons from performing procedures before they have mastered the technique [11, 80]. According to Schreuder et al. [11], the proctor should visit the hospital of the trainee so they can perform the surgery together, giving the trainee increasingly more responsibilities depending on his or her skills. While beneficial, however, proctoring remains a time-consuming and expensive method of teaching. As a result, telesurgery and teleproctoring have emerged as alternatives, although to date there are few data on its benefits and/or limitations.

Discussion

The concept of training and surgical education changed with the introduction of robotic surgery. Its appearance has created new challenges to ensure proper training and avoid subjecting patients to unnecessary risk. Among these challenges is the lack of information. Although our review and others found that simulators can be valuable training tools, there has been no comparative study of *all* the available simulators that could help hospitals choose the one most advantageous for their needs.

More importantly, there is no evidence that any one simulator is more effective than another [10]. Liss et al. [31] compared the MdVT and the da Vinci Skills Simulator. They found performance scores to be lower with the MdVT than with the da Vinci, but they reported that both simulators demonstrated good content and construct validity. Likewise, Abboudi et al. [10] published a systematic review of all the simulators available to robotic urologists. They reported that simulators, in general, provided a safe environment in which trainees could develop their skills. They also confirmed the overall validity, along with some evidence that the virtual reality simulator equaled the mechanical trainer for teaching the robotic suturing technique [81].

Even with these studies, there is a lack of standardization of the parameters that could help one compare the differences of the various simulators. Among these parameters, face validity remains relatively subjective, with no agreed-upon definition. Another parameter that is lacking is an agreed-upon definition of an "experienced robotic surgeon." This debate has continued with no consensus as to how many hours of using the console, the number of cases, and what degree of difficulty of cases are needed to designate someone an "experienced robotic surgeon." This needs to be well defined before drawing definitive conclusions for construct validity.

Another challenge involves the cost of the simulator, which is not negligible. In fact, most of the available simulators cost close to $100,000. Even the least expensive model, the SEP-Robot, is in the $40,000 to $45,000 (US$) range [9]. There is also the high cost of the double console, a cost that is considered by some to be excessive. A recent survey found that the majority of responders believed that the current cost for most simulators was unreasonable [9].

Of course, working with the robot on anatomic samples, animal models, or inanimate models can be costly as well, with estimates reported at $500 per hour [35]. Finally, as Steinberg et al. [82] have documented, there are high costs involved with the learning curve for complex robotic procedures, thus underlying the need for sophisticated training programs combined with a high caseload to overcome the learning curve.

Even after considering all of this, one question remains. For whom should the simulator be reserved? Simulators and basic training programs have been found to be most beneficial for novice trainees [83]. In fact, because these novices were also largely part of the "computer generation," the thinking was that this young generation was already well trained by video games, which made them a prime target for this new technology. It also gave a compelling reason for institutions to invest in a virtual reality platform [22]. Unfortunately, although previous video game experience has been shown to shorten the time to learn laparoscopic skills on a simulator [84], studies on robotic surgery have not found the same benefit [85–87].

This speaks to the need for a virtual training program used in tandem with a simulator. For institutions interested in purchasing a simulator without the virtual training, the Si system, the MdVT, and the RoSS system appear to be the more judicious choices as the da Vinci Skills Simulator requires use of the Si system. For advanced training, animal or cadaver models provide more accurate replication and thus can be more appealing [59]. Even if virtual reality simulation should become a component of robotic training, dry and wet laboratory exercises will continue to have value. Also of note, content and face validity have been recently proven for inanimate basic robotic skills [88], and the construct validity of the dry laboratory has been reported [89–91]. Additionally, the needle and suturing modules on a simulator are not considered realistic enough and do not involve anatomic representation or evaluation of functional consequences [22].

It is clear that virtual reality simulation lies somewhere between the animal model (limited in number) and the box trainer (low-fidelity simulator) [9]. The possibility of having a virtual instructor with standardized metrics would also be useful during the objective evaluation of the trainee as well as during the learning curve to assess the progress. This has previously been demonstrated with success in the aviation and defense industries [9]. Still, the simulator cannot be used if the robot is in use by a clinician—which remains a major limitation [31].

Since 2009, the American Board of Surgery began requiring that all general surgery graduates provide documentation of successful completion of Fundamentals of Laparoscopic Surgery (FLS) [9]. FLS is a validated, standardized education module designed to teach physiology, fundamental knowledge, and technical skills required for basic laparoscopic surgery, including simulation-based skills laparoscopy [9, 92, 93]. There is no equivalent of FLS in robotic surgery, although some groups have successfully incorporated part of the FLS model for robotic suture training [89]. Moreover, there are few official guidelines concerning the educational curriculum leading to robotic surgery certification.

There are performance metrics inherent in the available virtual-reality simulators that could serve as a possible adjunct when creating a standardized curriculum [9]. They are useful for certification, initial training, credentialing, and remedial training. Additionally, they could be used as a part of "warm-up" [8, 94]. In fact, training in a virtual environment has been shown to be effective when done before laparoscopic surgical procedures, leading to a significantly improved performance [95, 96]. Calatayud et al. [97] reported that a preprocedure warm-up using a virtual reality simulator was associated with better surgical performance than when not having a warm-up. Even in a busy surgical department, a preoperative warm-up time of 15 to 20 minutes [96] can be implemented into the daily routine, particularly if it can contribute to improved patient safety and better utilization of resources [97]. The da Vinci Skills Simulator is likely going to be the easiest to use for warming up because it is directly integrated into the console.

Any curriculum for robotic surgery needs to take into consideration the changing role of the mentor in robotics training. During conventional open and laparoscopic surgery, the mentoring surgeon is adjacent to the trainee and has the same view of the procedure [10]. The mentor is thus able to take over at any time the patient's safety is compromised. With robotic surgery, the mentor is not close to the trainee anymore, which is cause for concern. Alternative solutions include robotic courses, the use of a dual console, and simulation, all of which have a definitive role in the future of robotic surgical training [9]. There has also been a call from trainees who would like to have virtual reality as part of their regular training [18], although a survey from the Society of Urologic Robotic Surgeons shows that 40 % of responders have neither seen nor heard of virtual-reality simulators [9].

Conclusions

Even with a relative paucity of published reports on robotic simulators, and the lack of study in favor of one simulator over another, the trend is clearly in favor of virtual training. Virtual reality simulation should be part of the robotic curriculum, as should the use of a dual console, robotic courses, and proctoring. Various societies for robotic surgery are currently at work on a clear curriculum for the new generation of robotic surgeons, which hopefully will lead to standardization.

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