Robotic Surgical Education with Virtual Simulators

Roger Smith, PhD
Florida Hospital Nicholson Center
Celebration, FL
roger.smith@flhosp.org

Mireille Truong, MD
Florida Hospital Celebration Health
Celebration, FL
mireille.truong@gmail.com

ABSTRACT

The rapid advancement of robotic surgical technology and its implementation in minimally invasive surgical procedures has led to the need to develop more efficient and effective training methods, as well as assessment and skill maintenance tools for surgical education. Previous studies have shown that virtual simulation training is effective for improving laparoscopic surgical performance. However, few have evaluated the effectiveness of these types of simulators for improving robotic surgery proficiency.

A three-part evaluation of the available robotic simulators is being performed to address the value and possible applications of the devices. The first part is an objective review and comparison of the design and capabilities of all of the simulators, which provides base specifications to aid potential users with selection of the device that best meets their needs. The second part is a subjective opinion on the usability of the simulators, which will include a survey of various health professionals and medical students without prior experience using the simulation devices. The third part includes a two-month experiment to determine which simulator has the greatest positive impact on robotic surgical performance and the degree of skill retention over a period of inactivity.

This paper describes the results of the first part of this study. It provides comparative data on all three simulators - the da Vinci Skills Simulator (Intuitive Surgical Inc.); dV-Trainer (Mimic Technologies, Inc.); and RoSS (Simulated Surgical Skills LLC). This includes details about the curriculum, scoring method, system administration, visual resolution, validation, and support tools for the devices.

ABOUT THE AUTHORS

Roger Smith, PhD, is an expert in the development of simulation devices and training programs. He has spent 25 years creating leading edge simulators for the Department of Defense and Intelligence agencies, as well as accredited methods for training with these devices. He is currently the Chief Technology Officer for the Florida Hospital Nicholson Center where he is responsible for establishing the technology strategy and leading technology implementation. This includes identifying, executing and managing industry, military and federally funded simulation, modeling and training projects. He has served as the CTO for the U.S. Army PEO for Simulation, Training and Instrumentation (PEO-STRI); VP and CTO for training systems at Titan Corp; and Vice President of Technology at BTG Inc. He holds a Ph.D. in Computer Science, a Doctorate in Management, and an M.S. in Statistics. He has published 3 professional textbooks on simulation, 10 book chapters, and over 100 journal and conference papers. His most recent book is *Innovation for Innovators: Leadership in a Changing World.* He has served on the editorial boards of the *Transactions on Modeling and Computer Simulation* and the *Research Technology Management* journals.

Mireille Truong, MD, is a Minimally Invasive Gynecology Fellow at Celebration Health Florida Hospital, a Research Physician at the Nicholson Center and an Assistant Professor of Obstetrics and Gynecology (OB/GYN) at the University of Central Florida's College of Medicine. During her residency in OB/GYN at the University of Illinois at Chicago, she received a number of awards and honors, including Administrative Chief Resident, the American Association of Gynecologic Laparoscopists' Special Resident in Minimally Invasive Gynecology Award and Best Overall Excellence in Gynecologic Care Award. She has dedicated her time to education of medical students and physicians via an array of academic and teaching appointments, professional organization board positions, peer-reviewed publications and presentations at various national and international conferences. Her research interests include surgical education, robotic simulation and minimally invasive gynecologic surgery.

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BACKGROUND

For every complex and expensive system there emerges a need for training devices and scenarios that will assist new learners in mastering the use of the device and understanding how to apply it with value. In laparoscopic surgery, simulators have played an important role in improving the practice of surgery over the last 20 years (Schout, 2010; Wohaibi, 2010 et al). The same trends and values will likely apply to robotic surgery with the increased use of robotic technology for a growing variety of minimally invasive surgical procedures. The complexity, criticality, and cost associated with the effective application of the da Vinci surgical robot have stimulated the commercial creation of simulators which replicate the operations of this robot. The objective of this paper is to evaluate and compare the three commercially available robotic simulators shown in Figure 1:

- da Vinci Skills Simulator (Intuitive Surgical Inc.);
- dV-Trainer (Mimic Technologies, Inc.); and
- RoSS (Simulated Surgical Skills LLC).

Each of these possesses unique traits which make them valuable solutions for different types of users and learning environments.

DVSS dV-Trainer RoSS

Figure 1. Simulators of the da Vinci surgical robot

METHODS

Florida Hospital Nicholson Center owns and uses all three of these simulators. This cross-device access and experience is rare and provides unique comparative insight into the capabilities of all of the devices. We reviewed the users' manuals for the devices to collect details about each system and performed our own experiments with each device to create comparative materials across all devices.

We performed a systematic literature review on all three devices. The PubMed database of medical research was searched for all references to the devices through February 2013. References from retrieved articles were reviewed to broaden the search. The data extracted from these studies include training exercise modules, scoring systems, costs, educational impact and validation methods. We identified 32 studies investigating simulation in robotic surgery.

Finally, we submitted our comparative data on the systems to the manufacturers of each device to receive a review of the accuracy of the information.

The result of this work in this comparative review of the devices which evaluates the characteristics, exercise modules, scoring systems, costs, validity, advantages and disadvantages of each simulator.

RESULTS

Each of these devices is manufactured by a different company and provides a unique hardware and software solution for training and surgical rehearsal. The capabilities and features of each are summarized in Table 1.

Capabilities and Features

Da Vinci Skills Simulator (Intuitive Surgical Inc.)

The da Vinci Skills Simulator (DVSS) consists of a customized computer package that attaches to the back of the surgeon’s console of an actual da Vinci Si robot. This simulator connects to the surgeon’s console via a single proprietary networking cable identical to that used to connect the components of the actual robotic surgical system.

Advantages

Attached simulators of this type are usually referred to as “embedded trainers” because they take advantage of the equipment that has already been constructed, purchased, and installed for the operation of the real system. These kinds of simulators are especially common in military facilities which face limited space and weight constraints. They can significantly reduce the hardware that must be purchased solely for simulation purposes. The U.S. Navy uses these kinds of simulators aboard ships to reduce weight and space requirements, enabling them to train while the ship is at sea.

Another significant advantage of an attached simulator is that it allows the trainee to use the actual controls from the real system to control the simulation. This insures that the training experience is almost identical in feel to the real system, which can contribute to higher transfer of skills from the training sessions to the real system. Additionally, this minimizes the amount of time spent learning the unique functionalities of the simulator device and allows the trainee to focus the majority of his/her learning experience on skills acquisition and attaining proficiency. Finally, there is the cost advantage for the simulator device itself. Because much of the hardware and software expenses are already embedded in the real system, the simulator can be very economical to purchase.

Table 1. Robotic Simulator Feature Comparison

Features	DVSS	dV-Trainer	RoSS
System Manufacturer	Intuitive Surgical Inc.	Mimic Technologies Inc.	Simulated Surgical Systems LLC
Specifications (Simulator only)	Depth 7” Height 25” Width 23” 120 or 240V power	Depth 36” Height 26” Width 44” 120 or 240V power	Depth 44” Height 77” Width 45” 120 or 240V power
Specifications (Complete System as shown in Figure 1)	Depth 41” Height 65” Width 40” 120 or 240V power	Depth 36” Height 59” Width 54” 120 or 240V power	Depth 44” Height 77” Width 45” 120 or 240V power
Visual Resolution	VGA 640 x 480	VGA 640 x 480	VGA 640 x 480
Components	Customized computer attached to da Vinci surgical console	Standard computer, visual system with hand controls, foot pedals.	Single integrated custom simulation device
Support Equipment	da Vinci surgical console, custom data cable	Adjustable table, touch screen monitor, keyboard, mouse, protective cover, custom shipping container	USB adapter, keyboard, mouse
Exercises	35 simulation exercises	51 simulation exercises	52 simulation exercises.
Optional Software	PC-based Simulation management	Mshare curriculum sharing web site	Video and Haptics-based Procedure Exercises (HoST)
Scoring Method	Scaled 0-100% with passing thresholds in multiple skill areas	Proficiency-based point system with passing thresholds in multiple skill areas	Point system with passing thresholds in multiple skill areas
Student Data Management	Custom control application for external PC. Export via USB memory stick.	Export student data to delimited data file.	Export student data to delimited data file.
Curriculum Customization	None	Select any combination of exercises. Set passing thresholds and conditions.	Select specifically grouped exercises. Set passing thresholds.
Administrator Functions	Create student accounts on external PC. Import via USB memory stick.	Create student accounts. Customize curriculum.	Create student accounts. Customize curriculum.
System Setup	None.	Calibrate controls.	Calibrate controls.
System Security	Student account ID and password.	PC password, Administrator password, Student account ID and password.	PC password, Administrator password, Student account ID and password.
Simulator Base Price	$85,000	$95,000	$107,000
Support Equipment Price	$502,000	$9,100	$0
Total Functional Price	$587,000	$104,100	$107,000

Disadvantages

Attached simulators like the DVSS also come with inherent disadvantages to balance their positive traits.

The largest drawback is the availability and accessibility of a simulator which requires the real robotic system. An attached DVSS simulator cannot be used without access to a real surgeon’s console and therefore is only available for use when the robotic system is not in use. This implies that the trainee would only be able to use the simulator outside of normal operating room working hours and would need logistical access to the robot and the simulator. da Vinci robots are expensive devices which hospitals typically attempt to maximize use of in order to recoup their investment. In a very active surgical hospital, it can be difficult to obtain access to a surgeon’s console to support training with this simulator.

The DVSS is designed to connect to the surgeon’s console using the same proprietary networking cable that connects the major robot components. This makes the attachment and set-up process very easy for clinicians to master. However, it also means that the DVSS can only be used with the Si model surgeon’s console. The previous S and Standard models use a different set of cables, which are not compatible with the simulator.

Similar to the military’s experience with embedded and attached simulators, heavy usage of the DVSS comes with a corresponding heavy use of the surgeon’s console. The Army and Navy have discovered that these types of simulators put more usage hours on real equipment controls which lead to more maintenance costs for those devices. Given the possibility of regular and continuous simulation training with such as device in addition to actual surgical usage, the real equipment experiences usage rates that can be many times higher than normal for the equipment. Since the da Vinci systems operate under a maintenance contract that covers all services, the additional costs of maintenance are not born by the hospital owner, but by the equipment vendor. The primary impact to the owner would only be in the area of availability for both real surgeries and training events due to downtime associated with maintenance.

As mentioned under advantages, the cost of an attached simulator is typically much lower than other forms. However, this is countered by the fact that the customer must purchase or have available a real piece of equipment to support the use of the simulation.

dV-Trainer (Mimic Technologies Inc.)

The dV-Trainer is a separate, stand-alone simulator of the da Vinci robot. The surgeon's console, controls, and vision cart are mimicked in hardware, while a 3D software model replicates the functions of the robotic arms and the surgical space.

Mimic also developed the core simulator software for the DVSS and used the same package in version 1.0 of their own dV-Trainer. As a result, the exercises in those versions of the systems are nearly identical. The current version 2.0 of the dV-Trainer has a number of new exercises, which are not found in the DVSS, and the graphics have been upgraded so the visual presentation is no longer identical. The differences in visual presentation can be seen in the figures later in the paper.

The dV-Trainer consists of three major pieces of equipment and a number of smaller support pieces. The largest pieces are the "Phantom" hood which replicates the vision and hand controls of the da Vinci surgeon's console, the foot pedals of the surgeon's console, and a high-performance desktop computer which generates the 3D images and calculates the interactions with the surgeon's controls. Smaller support equipment includes a touch screen monitor, keyboard, and mouse to enable an instructor to guide the student through exercises and allow an administrator to manage the data that is collected.

Because the dV-Trainer replicates both the hardware and software of the da Vinci robot, it is a much larger system than the DVSS alone, though smaller than a real surgeon's console with the DVSS attached. It has the advantage of providing a training system that is completely independent of the need for any piece of the real surgical robot. The simulator can be configured to imitate either the S or the Si model of the da Vinci robot.

The disadvantage of this kind of system is that the simulated hardware is somewhat different than the real equipment and does not exactly replicate the feel of the real physical equipment. There is always a trade-off between lower price and perfect accuracy of a simulator. Also, the simulator must be updated separately when the real equipment is modified.

Robotic Surgical System (Simulated Surgical Systems LLC)

The RoSS is also a complete, stand-alone simulator of the da Vinci robot. This device is designed as a single piece of hardware that has a similar design to the surgeon's console of the robot. The hardware device includes a single 3D computer monitor, hand controls that are modified commercial force feedback devices, pedals that replicate either the S or the Si model of the da Vinci robot, and an external monitor for the instructor. Customers must purchase either the S or Si version of the device.

The company has developed a set of 3D virtual exercises that are unique from those found in both of the other simulators. They also provide an optional video-based surgical exercise in which the user is guided through the movements necessary to complete an actual surgical procedure. At this writing, these modules are available for radical prostatectomy, cystectomy, and hysterectomy. These guided videos take advantage of the force feedback capabilities of the hand controllers to push and pull the student's hands to follow the simulated instruments on the screen. They require the student to perform specific movements accurately during the video before the operation will proceed.

Exercise Modules

The exercise modules in each simulator are organized into hierarchical menus according to the surgical skill being addressed and the complexity of the exercise (Table 2). Each simulator provides on-system instructions for each exercise in the form of textual documents and narrated step-by-step video demonstrations. Upon completion of each exercise, the system automatically proceeds to a scoreboard showing the student's performance on the exercise.

Table 2. Comparative Simulator Exercise Categories

DVSS	dV-Trainer	RoSS
Surgeon Console Overview	Surgeon Console Overview	Orientation Module
Endowrist Manipulation	Endowrist Manipulation 1	Motor Skills
Camera and Clutching	Endowrist Manipulation 2	Basic Surgical Skills
Energy and Dissection	Camera and Clutching	Intermediate Surgical Skills
Needle Control	Energy and Dissection	Hands-on Surgical Training
Needle Driving	Needle Control	
Troubleshooting	Needle Driving	
Games	Games	
Suturing Skills	Suturing Skills	

DVSS

The DVSS contains 35 exercises organized into nine categories. These begin with introductory video and audio instructions on how to use the robotic equipment, and move through progressively more difficult skills.

dV-Trainer

Most of the simulation software for Intuitive's DVSS was developed by Mimic Technologies. Therefore, version 1.0 of the DVSS and the dV-Trainer contained nearly identical exercises, closely matching menu systems, and identical scoring mechanisms. However, over time the two sets of software have diverged and the current versions of the simulators differ in functionality and appearance. The current version of the dV-Trainer (v 2.0) contains 51 exercises organized into nine categories.

Though many of the exercises are identical between the DVSS and the dV-Trainer, the graphics resolution and details have been improved in version 2.0 of the dV-Trainer software. Since this system is driven by a commercial PC which can be upgraded rather easily, it is possible for the software to evolve and be replaced more easily than for a custom hardware package like the DVSS which would require upgrades to some of the components inside the device.

RoSS

The RoSS simulator contains 52 unique exercises, organized into 5 categories, and arranged from introductory to more advanced, just as in the other two simulators. The RoSS system of exercises is unique in that they list fewer named exercises, but provide three different difficulty levels for most of them (i.e. Level 1 is the easiest, Level 2 is intermediate, and Level 3 is advanced).

The RoSS contains a unique capability that is not found in either of the other simulators called "Hands-on Surgical Training" or "HoST." This is an integration of surgical skills exercises with a video of an actual surgery. Videos of actual surgical procedures play in the surgeon's visual space, overlaid with animated icons which instruct the student to perform specific actions during the progression of the surgery video. The necessary actions are prompted with audio instructions. For the HoST exercise to progress, the student must perform the specific actions at specific times. The simulator will pause the video and allow the student to repeat the action until it is performed as required by the instructions.

The hand controllers of the RoSS simulator are modified versions of a commercially available 3D haptic input device called the Omni Phantom™. This product uses internal motors and gears to apply haptic feedback to the hand movements of the user. For the HoST exercises, the simulator uses this capability to move the student's hands in sync with the movements of the surgeon's instruments in the master video.

Proficiency Scoring System

Each of the three simulators provides a different scoring method. All three use the host computer to collect data on the performance of the student at the controls in multiple performance areas. With this data, they provide a score for specific performance traits, as well as combining all of these into a single composite score of performance for the entire exercise. The algorithm used to create this composite score is described in the user's manuals of each of the simulators. Examples of each of these scoreboards are shown in Figure 2.

DVSS	dV-Trainer	RoSS

Figure 2. Example Scoreboards from Each Simulator

In addition to the objective metrics that can be collected by the computer, the developers of each simulator have been challenged to provide thresholds which indicate whether the student's score is considered a "passing" or "failing" performance. All three have identified threshold scores which would indicate acceptable and warning scoring levels. These are commonly interpreted as "passing" (above acceptable threshold) and "failing" (below warning threshold), with a "warning" area between the two thresholds. These thresholds create green, yellow, and red performance areas, which can be used to visually communicate the quality of the student's performance in each area of measurement. Each simulator also provides a single composite score for the entire exercise.

DVSS

The DVSS performance scoring method has a number of metrics, which are applied to every exercise and others which are only used for exercises in which they are relevant. Table 3 presents the metrics, which are applicable to all exercises. For details on the more specialized metrics, the reader may consult the user's manual for the simulator.

Because the DVSS is a closed, turn-key system with an ease of use similar to the actual surgical robot, most of the data displays and threshold adjustments found in the other simulators are not available in this device. Most simulator settings are determined by the manufacturer and cannot be changed by the user.

Table 3. DVSS and dV-Trainer Scoring Method

Overall Score	Composite evaluation of the exercise performance.
Time to Complete	Number of seconds to complete the exercise.
Economy of Motion	Number of centimeters of instrument tip movement.
Instrument Collisions	Number of times that the instruments touched each other.
Excessive Instrument Force	Number of seconds that excessive robotic force was applied against objects in the environment.
Instrument Out of View	Number of centimeters that an instrument tip moved outside of the viewing area.
Master Workspace Range	Radius in centimeters than contains the movement of the instrument tips.
Drops	Number of objects dropped from the grasp of the instruments.

dV-Trainer

Originally, the DVSS and the dV-Trainer shared the same scoring method, but more recent versions of the dV-Trainer offer both this original "version 1.0" scoring method, as well as a new "version 2.0" method based on the proficiency measured from experienced surgeons. The skills measured are the same (Table 2), but the interpretation of those into a score is different. The instructor can select the preferred scoring method for each curriculum that is constructed in the dV-Trainer.

Users will notice that the newer scoring method uses total points earned rather than percentages. The passing and warning thresholds can be adjusted by the administrator. The philosophy, validity, and effects associated with these settings are more detailed than is necessary for understanding the use of the simulator. Interested readers should consult the user's manual and published literature for details on the two scoring mechanisms.

RoSS

The principles behind the scoring system on the RoSS are the same as those for the DVSS and the dV-Trainer. However, most of the metrics collected are different. The standard measurements are shown in Table 4.

Table 4. RoSS Scoring Method

Overall Score	Composite evaluation of the exercise performance.
Camera Usage	Optimal movement of camera.
Left Tool Grasp	Optimal number of tool grasps with left hand tool.
Left Tool Out of View	Distance left hand tool is out of view
Number of Errors	Number of collision or drop errors in an exercise.
Right Tool Grasp	Optimal number of tool grasps with right hand tool.
Right Tool Out of View	Distance right hand tool is out of view.
Time	Time to complete the exercise.
Tissue Damage	Number of times that instruments damaged tissue with excessive force or unnecessary touches.
Tool-Tool Collision	Number of times tools touched each other.

Like each of the other simulators, there are multiple displays of the performance data for a student. The initial display presented at the completion of an exercise shows a horizontal bar which is colored green, yellow, or red to indicate passing or failing. The magnitude of the bar is a rough measure of the quality of performance. Additional displays show the numeric score and its relative position to a passing threshold.

Validation of Devices

Validation studies serve to determine whether a simulator can actually teach or assess what it is intended to teach or assess. In medical simulation, there are generally accepted validity classifications, which include face, content, construct, concurrent and predictive validity (McDougall, 2007). Face and content validity are considered subjective approaches while the other three are objective approaches to validation.

Table 5 provides a summary of the published validation studies for these simulators. All three have publications establishing face, content, construct, and concurrent validation. There is only one published study on the predictive validity of the DVSS (Hung, 2012). Recent presentations also explore the validity of the RoSS curriculum (Stegemann, 2013) and the RoSS' HoST procedural modules (Ahmed, 2013).

Table 5. Validation of robotic surgical simulators

Validation	DVSS	dV-Trainer	RoSS
Face	*Hung 2011* *Kelly 2012* *Liss 2012*	*Lendvay 2008* *Kenney 2009* *Sethi 2009* *Perrenot 2011* *Korets, 2011* *Lee 2012*	*Seixas-Mikelus 2010* *Stegemann, 2012*
Content	*Hung 2011* *Kelly 2012* *Liss 2012*	*Kenney 2009* *Sethi 2009* *Perrenot 2011* *Lee 2012*	*Seixas-Mikelus 2010* *Colaco, 2012*
Construct	*Hung 2011* *Kelly 2012* *Liss 2012* *Finnegan 2012*	*Kenney 2009* *Korets, 2011* *Perrenot 2011* *Lee 2012*	*Raza, 2013*
Concurrent	*Hung 2012*	*Lerner 2010* *Perrenot 2011* *Korets 2011* *Lee 2012*	*Chowriappa, 2013*
Predictive	*Hung 2012*		

CONCLUSIONS

The three simulators described in this review article are complex systems, which are significantly less costly than the actual da Vinci robotic surgical system and can be operated at a fraction of the cost of the instruments required for this robot. There are currently no available studies comparing the three simulators head-to-head and therefore until those studies are performed, no universal recommendation can be made for one device over the other, but rather a decision to use one simulator over the other should be based on unique and individual needs.

This article represents the first part of a comprehensive analysis of robotic surgical simulators. The second part is a subjective opinion survey on the usability of the simulators. Subjects for this survey will include attending surgeons, fellows, residents, and medical students without prior experience using the simulation devices. The third part will include a select group of surgical fellows will participate in a two-month experiment practicing on one of the simulators while their performance is measured every two weeks to assess for changes and maintenance of skill levels. The experiment is designed to determine which simulator has the greatest positive impact on robotic surgical performance and the degree to which those improvements are retained across a period of inactivity.

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