Robotic Simulators: A Case for Return on Investment

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ABSTRACT

Simulation has been integrated into the education and certification process in aviation and military arenas with significant success in providing cost effective training. The transition from the apprenticeship model to simulation has been slower in the field of medicine with cost, lack of curricula and high fidelity exercises and equipment being the main reasons. With recent improvements in all areas, cost remains a significant challenge.

This report describes our novel analysis of the return on investment (ROI) that can be achieved through the inclusion of simulator use within a robotic surgery business practice and as an alternative source of training revenue. Information was gathered through an extensive literature review and expert interviews for the development of an interactive calculator for institutions to utilize when considering an investment in robotic surgery simulators.

This ROI model presents the core improvements to existing operations which may be realized through the use of simulators of robotic surgery. Category headings include simulator investment costs, surgeon productivity, surgeon health, hospital costs, and other training costs. The user of the model is able to enter their own numbers for their unique facilities. The spreadsheet model will calculate the costs and benefits associated with each area, create category subtotals, and then an overall total for all areas. Using these numbers, it can then calculate an ROI percentage for the simulators. This model represents one tool to assist organizations in making the investment in these devices and training programs.

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. 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.

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INTRODUCTION

Creating a viable robotic surgery practice within a hospital is an expensive and risky endeavor. The investment in equipment, facilities, personnel, and process modification is significant, amounting to millions of dollars in the early years of a program. Many hospitals make this investment with a limited understanding of how best to structure a robotics practice and the probability of achieving a positive return on this investment. At the business end of a decision to create a robotic surgery practice, the hospital has the goals of optimizing the utilization of the robotic operating room, reducing costs, and ensuring patient safety. Training to and maintaining the competency of the surgeons performing the procedures has a direct impact on these areas, allowing the inclusion of simulators in the robotic business unit to make valuable contributions. The proposed effects are summarized in Figure 1. This report describes our analysis of the return on investment that can be achieved through the inclusion of simulators and their regular use within a robotic business practice; and as an alternative source of training revenue.

Increasing +	Decreasing -
Surgeon Productivity	Training Costs
Surgeon Stamina	OR Costs
Surgeon Competence	Medical Errors
Surgeon Certification	Instrument Breakage
Surgeon Career Length	Insurance Costs
OR Utilization	

Figure 1. Summary of Simulation Effects on Surgical Practice

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. Intuitive Surgical's da Vinci robot is just such a system. It is currently the only FDA approved device for laparoscopic robotic surgery on human patients. Despite the 1.5 to 2 million dollar price tag, the device has seen rapid distribution and its implementation has led to the need to develop more efficient and effective training methods, as well as assessment and skill maintenance tools. In laparoscopic surgery, simulators have played an important role in improving the practice of surgery over the last 20 years (Schout and Hendriks, 2010; Wohaibi and Bush, 2010). The same trends and values will likely apply to robotic surgery.

The complexity, criticality, and cost associated with the application of the da Vinci surgical robot have stimulated the commercial creation of simulators which replicate the operations of this robot. There are currently three different simulation systems available for training and developing skills in robotic surgery: 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. Investment in the simulators alone represents a major capital investment as costs range from $100K (RoSS/dV-Trainer) to $600K (da Vinci Skills Simulator) per device and its associated support equipment. Coupled with increases in direct costs from operating room time and supplies, (Venkat and Chen, 2012; Pasic and Rizzo, 2010; Bolenz and Gupta, 2010; Barnett and Judd, 2010; Holtz and Miroshnichenko, 2010) robotic surgery implementation can have a profound impact on hospital finances. This doesn't include costs associated with ensuring patient safety and surgeon training. From a business perspective, a hospital, college of medicine, or robotic practice should identify a return that will be achieved with the purchase of these devices.

History of Simulation

Rehearsal and simulation has been one of the primary means of developing and maintaining proficiency in specific skills for thousands of years. Lectures and written materials are the primary means for developing cognitive knowledge, but these are not effective at instilling psychomotor skills in any field. The skills needed in the hands, body, and coordination with the mind must be developed through practice. Rehearsal in a non-lethal environment has become the standard of practice for learning in military warfare and aviation. The lives of soldiers and pilots today are considered of significant value to demand a structured training program and measure of proficiency before entering a life threatening situation. Given the technology that has emerged in the late 20th and early 21st centuries, the means of rehearsal have shifted from drills toward events that are mediated by computers with the ability to measure performance and provide constructive feedback on means to improve that performance. Implementation of direct practice on simulators has led to significant quality improvements and a reduction in training costs to the tune of hundreds of millions of dollars. There is a 30 to 40 year history of success documented in the military literature, specifically regarding its return on investment. On average simulators cost 5-20% of live training and can reduce the length of training by 10-30% (Fletcher and Alexander 2013). Simulation has also been found to be well liked by trainees and found to be comparable to live training in terms of experience as well as outcome (Worley and Simpson 1996).

Simulation devices are similarly a prominent tool in medical and surgical education. From the most primitive stuffed dolls with anatomical markings used in ancient Chinese societies, to the most current computer driven, three dimensional representations of living tissue, simulators have been helping to train surgeons for over a thousand years . While there are parallels between the military and medical fields regarding the involvement of human life and the need for structured high fidelity training, there are some unique challenges. There are many confounders in medicine and the seemingly direct relationship between simulation and improved patient outcomes and reduction in costs is not robust. So, while most agree that simulation is a necessary requirement for surgical training, the lack of evidence coupled with the costs of device and curriculum development have led to a slower adoption of simulation in surgical education when compared to industry. One of our goals is to use the lessons from our military and aviation industries in conjunction with published literature to identify key variables that impact the ROI of robotic surgical simulators and provide a loose framework for how simulators can be better utilized to achieve financial, educational, and patient safety benefits. We will focus on the concept of return on investment (ROI) for these simulators, not on the capabilities of one specific device. Our goal is to assist the purchasers and users of these devices in determining whether such a device is a sound financial investment.

Published Literature

There are very few studies evaluating ROI for the simulators of the robot. There is one article directly evaluating the RoSS simulator (Rehman and Raza 2013) where annual training hours were converted to training time on a robotic console. In that study, the use of the stand-alone simulator resulted in cost savings of $600,000. Animate lab training of the same duration would have cost approximately $72,000 annually to train 100 people each year. The remainder of the studies look solely at laparoscopic simulators. For example, in March 2004, Frost & Sullivan Inc. conducted a ROI study on three training simulators sold by Immersion Medical. Specifically, the data regarding the Laparoscopy AccuTouch System was published. The Laparoscopy AccuTouch System uses advanced 3D technology and graphics to re-create the procedures and environment of abdominal laparoscopic surgery. Using reported median values from survey data, financial benefits were estimated at $168,767, based on annual costs $76,000, with an estimated payback period of 169 days. Also somewhat related, is a review article by Leddy et al that reviewed the published cost analyses of robotic surgery for both urology and pediatric surgery, in an effort to develop a novel model for determining return on investment. The premise for the model was that reduction in costs directly relate to the ability of the technology to reduce hospital length of stay. Surgical volume can be limited by the availability of hospital beds, in which shorter hospital stays lead to greater bed availability, which can lead to more procedures being performed. It also acknowledged the learning curve of robotic surgery and the expectation for OR times to decrease with improved technology, surgical technique, and time.

METHODS

The first step was to identify, at a basic level, the main effects that robotic simulation would have on a healthcare organization. We found that the use of a simulator can have a direct impact on at least three major, but separate parts of the healthcare delivery process (Figure 2).

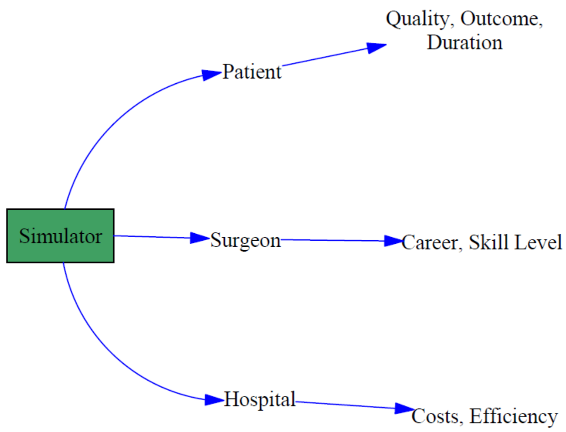

Figure 2. Robotic Surgery Simulator Impact Areas

The first, and most important, is patient outcome. The use of a simulator can potentially improve patient outcome by allowing the surgeon to perform more effectively and efficiently with fewer adverse events.

The second is the impact on the surgeon. He or she may find that the ability to use the robot effectively impacts their career with additional options that can be offered to the patient and to a potential hospital employer. It may also reduce the long-term wear and tear on the surgeon's body due to improved ergonomics, making it possible to continue practicing surgery for a longer period of time.

Third is the effect that it will have on the costs and efficiency of the business practice. Simulator trained surgeons may perform procedures more rapidly, with less error, and lower instances of equipment breakage. This ties directly back to improved patient outcomes.

With this as a foundation, we used a diagramming method popularized by Jay Forrester at Massachusetts Institute of Technology (MIT) to explore the interrelationships between a large number of variables within the complex and dynamic hospital surgical program. This method identified variables which react almost immediately to changes in training offered to robotic surgeons as well as longer-term variables which may take years to emerge as measurable returns on the investment. These relationships can be grouped and organized as shown in Figure 3. Note that each variable is associated with a calculable financial outcome. This model was useful in identifying the factors which contributed to ROI in a first, second, and third level of separation. It also motivated discussions around the financial and non-financial variables that were changing with the incorporation of simulation.

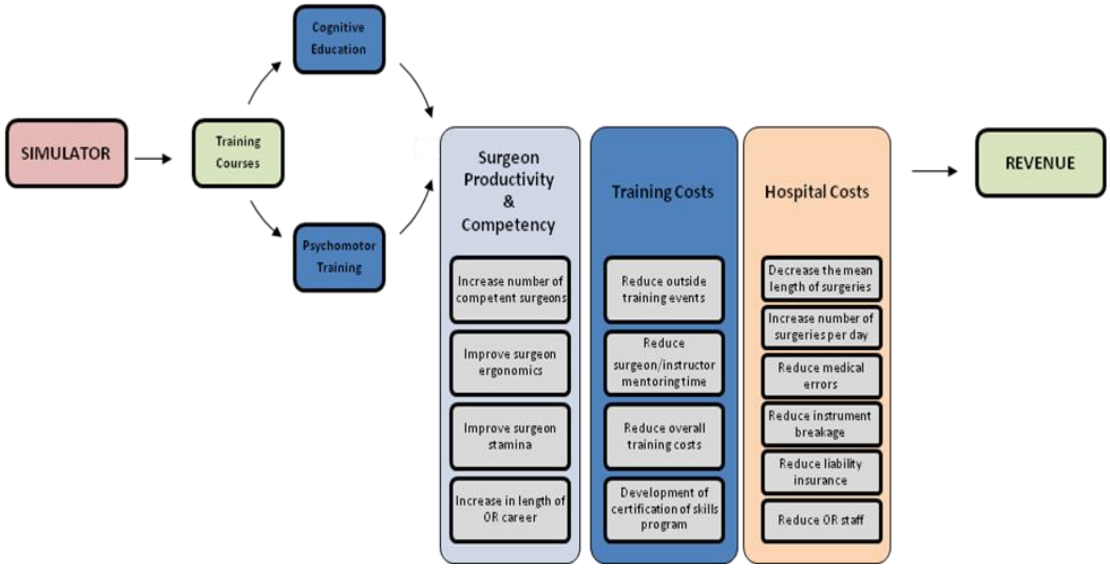

Figure 3. Effects of Simulation-based Training on Robotic Surgery Business

Expert Opinion

Twelve expert interviews were then conducted at several simulation centers around the country and internationally to further expound upon the model, including identifying and quantifying variables. Surgical leaders interviewed included Randy Fagin MD, Texas Institute of Robotics; Brendan Sayers PA, University of Texas – Southwestern; Arnold Advincula MD, Celebration Health; Thomas Lendvay, MD, University of Washington College of Medicine; Robert Sweet, MD, University of Minnesota College of Medicine; Col Timothy Brand, MD, Madigan Army Medical Center; Jacques Hubert, MD, University of Lorraine Medical School; Dimitrios Stefanidis, MD, Carolinas Healthcare System; Martin Martino, MD, Lehigh Valley Health Network; Mona Orady, MD, Cleveland Clinic; John Lenihan, MD, MultiCare Health Systems; and Michael Pitter, MD, Newark Beth Israel Medical.

There were several common themes identified from the expert interviews. Most agreed that having a defined curriculum was imperative to successful training and that it should be identified prior to purchasing a simulator. These robotic training curriculums consisted mostly of manufacturer-developed didactic education with a combination of simulator and/or dry lab assessment. It was also clear that there were a variety of successful arrangements for location and proctoring of a robotic simulation curriculum. The majority utilized a combination of the dVSS and the dV-Trainer. Only one program had a dedicated training console, therefore most simulation with the dVSS was limited to nights and weekends. Simulation was most often a part of resident and fellow curriculums but approximately 50% of the sites also had attending level programming. Simulator value was also identified to be tied directly to the accessibility of the necessary equipment.

They verbalized a strong need for studies evaluating correlations between simulation and improved clinical outcomes, determining the ideal length and intervals for simulation training, and comparative studies between institutions with and without simulation centers. In addition to maintenance and certification, curricula could also be used for remediation training following complications. Software interests surrounded the development of procedure specific training and increasing complexity of these procedures. Several believed that simulation could be used globally to decrease insurance costs and increase reimbursements.

Simulator ROI Model

Using the information in the system dynamics diagram, we created a basic model of the ROI with short-term, measurable returns. The model is populated with average numbers from the literature and the authors' institution, but the user is able to enter specific numbers representing their unique facilities. Users enter data for their specific institution and the model calculates intermediate values and an annual return for Years 1 & 2 following the investment. Interested readers may request the full calculator with relevant appendices from the authors at no charge. Figure 4 illustrates part of the data entry and calculation fields for the calculator. Table 1 provides a sample of the variables and returns that are possible from a simulator-based training program.

Robotic Simulator Return on Investment Model				
	User Entered Data	*Orange Fields*		
	Model Calculated Data	*Grey Fields*		
			Overall Average	
		Initial Investment	**Annual**	**Totals**
Simulator Investment Costs				
	Cost of Simulator	$100,000	$0	
	Number Purchased	4	4	
	Annual Maintenance Fee	$0	$10,000	
	Simulator Investment	$400,000	$40,000	
	Annual Maintenance Fee	$0	$10,000	
	Facility Costs	$100,000	$5,000	
	Staffing Costs	$20,000	$50,000	
	Supplies & Materials	$1,000	$200	
	Investment	$521,000	$105,200	$105,200
Surgeon Productivity				
	Number of Surgeons Trained		2	
	Mean Length of Operation		2	hours
	Time Saved per Procedure		20	minutes
	Length of Surgical Day		8	hours
	Surgeries per day		8	
	New Free Surgery Time per day		2.67	hours
	Added Surgeries per Day		1	
	Revenue per Surgery		$32,000	
	Additional Revenue per day		$32,000	
	Surgical Days		100	per year
	Additional Revenue per Year		$3,200,000	$3,200,000
Surgeon Health				

Figure 4. ROI Calculator (Partial Screenshot)

Table 1. ROI Calculator Sample Variables

INVESTMENT	Cost (Year 1)	RETURNS		Benefit (Year 1)
Cost of Simulator	**$100,000**	*Surgeon Productivity*	Number of Surgeons Trained	**2**
Annual Maintenance Fee	**$0**		Mean Length of Operation (Hours)	**2**
Facility Costs	**$100,000**		Time Saved per Procedure (Minutes)	**20**
Staffing Costs	**$20,000**		Length of Surgical Day	**8**
Supplies & Materials	**$1000**		Revenue Per Surgery (Includes Admission)	**$32,000**
			Surgical Days per Year	**100**
		Surgeon Health	OR Stamina (Hours)	**6**
			Improved Stamina (Hours)	**1**
		Hospital Costs	Liability Insurance	**$100,000**
			Competence Discount	**5%**
			Average Instrument Breakage	**$5,000**
			Breakage Reduction Factor	**10%**
			Surgical Error Rate	**1%**
			Error Improvement Rate	**10%**
		Training Costs	OR Training Time per Day (Hours)	**1**
			Number of In-house Courses	**6**
			External Training Event Cost (w/Travel)	**$6,000**
			Number of External Events	**1**
			Training Reduction	**50%**

Listed below are the many factors to be considered in each cost category as well as limitations to the calculator.

Investments

The costs associated with adopting a simulator training program include:

Cost of Simulator. The initial investment in purchasing the simulator device. The price point for many surgical simulators is in the neighborhood of $100,000 per device.

Annual Maintenance Fee. Most devices include one year of maintenance or service warranty with the purchase of the device. In following years, there is an annual fee to cover the installation of updates and repairs to the device. One must also allow for additional repairs beyond the normal maintenance.

Facilities Costs. The equipment needs to be housed in a location that is conducive to sufficient access and training. A dedicated space is preferred, but some institutions use a shared space model to reduce this cost. This impacts the degree to which surgeons can use the devices on their own initiative which directly impacts training efficiency.

Staffing Costs. Most simulator devices require a knowledgeable trainer to instruct the surgeons on the use of the device and to facilitate data collection and the tracking of performance improvement. This staff person does not necessarily have to be dedicated to the robotic simulators, but can be a shared resource that has additional duties in the hospital system. The staffing cost can vary widely depending on the type of assignment used, such as hiring new personnel versus training an existing employee. An additional consideration would be the loss of revenue from physicians, nurses, and other medical professionals during training sessions.

Supplies & Materials. Because robotic simulators are electronic and use no real consumables like suture pads, needles, and fluids, the supplies and materials for continuing to use them is minimal. Some typical supplies include: power strips, extension cords, cleaning wipes, spare parts, computer thumb drives, and computer adapters.

The investment in simulator programs is typically highest at initial purchase for the equipment and much lower for each ensuing year. Therefore, the model separates the first year from years following. The expenses in years 2, 3, 4, etc. appear to be very similar. At this point there is little data on equipment fatigue with use. There is only published data on the RoSS. Master controllers and the pinch devices need to be replaced at 180 and 360 hours of use respectively (Rehman 2013). We are therefore not able to identify the effective useful lifetime of a simulator device or a significant upturn in costs due to increased maintenance in later years. Insight into what to expect in robotics may be found in the operating expenses for laparoscopic training simulators which have been in use for many more years.

Returns

The returns that can be experienced through the implementation of a robotic simulator training program fall into four major categories: surgeon productivity, surgeon health, hospital costs, and training costs. Each of these has many variables which contribute to financial returns.

Surgeon Productivity. The primary goal for most organizations creating a simulator training program is to increase the productivity of their surgeons. A model of surgeon productivity begins with the number of surgeons who are trained and the amount by which this training can speed up a typical operation. Reducing the time required to perform a surgical procedure can contribute to multiple variables. First, it may reduce staffing costs by allowing the staff that supports the surgeon to move on to other activities, or to work fewer paid hours during the day. In some cases, it may reduce total OR staffing due to the ability of the surgeon to control both the camera and the surgical arms concurrently. Second and most importantly, if the reduction is large enough, it may open a window in the OR schedule which is sufficient to perform an additional operation during the day. Third, if simulator-based training can reduce the variance in surgical times for procedures, it will make the scheduling of procedures more accurate. This would reduce the "slippage" that occurs in the daily schedule because a procedure takes twice as long as was scheduled. Smaller variances lead to more efficient scheduling which can reduce staffing and facilities costs. This model focuses on the impact of reducing surgical time sufficiently to open a window for an additional surgery. The impacts of variance across multiple instances of similar procedures is worthy of an entire dedicated study and is not included.

Surgeon Health. Robotic systems significantly reduce the physical workload experienced by traditional open and MIS surgeons. All surgeons have a level of stamina that allows them to perform for a specific number of hours each day. Upon reaching this point, the muscles and mental focus of the surgeon are diminished. Continuing to operate can bring risks both to the health of the patient and the surgeon.

Rehearsal in a simulator has the effect of training the muscles which are used in surgery. Familiarization with the tasks also reduces the amount of mental and physical effort that is required to complete each procedure. The extension of surgeon stamina and the reduction in energy expended can both lengthen the number of hours that a surgeon is able to perform optimally.

This physical and mental training can extend the surgical day for a specific individual. It may also extend the length of the surgeon's operating career by reducing repetitive stress injuries and aging due to mental stress. The cumulative impact on the length of careers cannot be calculated at this point. Exploration of this effect is left for future researchers.

The model of surgeon health included in the ROI model in this paper is limited to daily extensions of operating time.

Hospital Costs. The model identifies four major hospital cost categories which may be reduced due to improved surgeon competence: instrument breakage, liability insurance, surgical error rate, and training costs.

Inexperienced surgeons can break the controls of the robot through the exertion of too much force and fighting against the electrical and mechanical components of the robot. When the surgeon damages the robot, the cost of many (but not all) repairs is covered by the maintenance agreement; but the significant cost to the hospital is in the disruption that occurs in postponing or rescheduling an operation because the robot is no longer operable. Inexperienced surgeons can also damage the surgical instruments held by the robot. Each of these typically costs between $1,200 and $2,500. Frequent abuses come from forceful instrument collision and friction along the shafts. Simulator training can develop skill and dexterity with an instrument which prevents this from happening.

As medicine becomes even more evidence based, there will be the opportunity to quantify the liabilities associated with specific surgeon competence levels. This may allow surgeons who can document additional training and acquired competence to reduce their medical liability costs when compared with surgeons who have less training. Experts whom we interviewed for this study indicated that they had already begun annual mandatory simulation-based exams as part of their internal risk management plan with the hope of realizing insurance savings in the future.

The competence that comes from simulator-based training can reduce the number of errors that are made in robotic surgery. Errors can require a return to the operating room for a procedure which generates no additional revenue.

There are multiple forms of training used to acquire, maintain, and extend the expertise of the surgeons. When a simulator program is introduced it can reduce the need for alternate forms of training. One popular form of robotic training today is through visitation and instruction in the OR itself. This long established and traditional practice is used in all surgical specialties. But, it is known that "in OR" training results in an extension of the time to complete the procedure (Koperna 2004). Additional time is required to explain the procedure and what is happening to the trainee. Given the high cost of OR time, a reduction in OR-based live training can generate meaningful savings for a hospital.

There are two typical forms of outsourced training. The first is bringing an instructor into the hospital system to instruct the surgeons. The second is sending the surgeons to other facilities or congress meetings to acquire the skills they need. Both of these are subject to reductions when similar skills can be acquired and measured in the simulator program. Once equipped and experienced, the organization can also become a vendor of training services as well as provide simulator rentals without the responsibility and costs of providing training staff and materials. Other organizations may seek out such rental agreements to avoid the capital purchasing costs.

Two additional considerations include team training and surgical assist training. Some of the increased length of robotic surgical cases is due to set-up time and docking times. Ensuring proper training of surgical assists and nursing in addition to physician training may decrease these times and costs.

Upper Limit

There are upper limits to the improvements that can be achieved. For actual surgical procedures, these are driven by the number of robots available to perform surgery. Increasing surgeon availability beyond the capacity of the robotic OR will not provide improvements. An additional consideration is the availability of the robotic simulator for daily use or the training efficiency of the robotic simulator. If an institution chooses to invest in a DVSS trainer but does not have a dedicated training console, then training availability will be limited when compared to those with a standalone trainer.

CONCLUSION

In 1927, William Mayo famously stated that, "There is no excuse for the surgeon to learn on the patient." In the ensuing decades, there have been many advances in the education of surgeons. Simulators offer the next improvement along this path with capabilities that are very difficult to match through any other mode of training. We are entering a period in which competence-based learning is becoming the standard. This is an environment in which simulators possess undeniable advantages and empower the preparation of demonstrably competent surgeons.

Robotic simulators are available but are not yet a standardized part of the training process. As the airlines and the military discovered in training pilots and combat personnel, simulation devices provide so many advantages in the learning process that they have become a mandatory part of those training curricula. The expectation is that the same will occur with robotic simulators over time.

We recognize that many of the proposed financial and non-financial benefits are theoretical and that simulation in a well-designed curriculum purports different benefits than just the simulators themselves. There is an absence in the literature regarding the direct correlation between simulation and many of the positive impacts noted in this study. Despite this absence, there is evidence of three things that make these impacts real: the evidence of transfer of training with simulation as evidenced by validation studies, the presence of a steep learning curve (trends of up to 100 cases before true competency is achieved), and the improvements in surgical outcomes with high volume surgeons and centers. We also know that hospital systems and practices are highly variable and all factors cannot be identified and/or quantified financially. If there is not a direct return on investment, we are not suggesting that simulation based education is of no value. We designed the calculator to try to capture simulation effects on a business practice not only to justify the investment but to identify best practices and ways to implement robotic surgical curriculum in a meaningful and comprehensive way. These concepts should guide future research.

To summarize, the use of simulators in training robotic surgeons requires an investment in equipment, staff, facilities, and supplies. But it also offers a return on this investment in surgeon productivity, surgeon health, hospital costs, and other training costs. The realizable returns will vary by institution based on the specifics of implementation and the existing ecosystem in which they are inserted. The ROI model in this report is one tool to assist in calculating the return that can be expected by organizations that make the investment in these devices and training programs.

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