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Simulation-based robot-assisted surgical training: A health economic evaluation

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ABSTRACT

Objective: To determine the overall cost effectiveness of surgical skills training on Robotic Surgical Simulator (RoSS).
Methods: This study evaluates the cost analysis of utilizing RoSS for robot-assisted surgical training, at Roswell Park Center for Robotic Surgery. Trainees were queried for time spent on the RoSS console over a period of 1 year, starting from June 2010 to June 2011. Time spent was converted to training time consumed on robotic console, resulting in loss of OR time and revenue. The mechanical durability of the RoSS was also determined.
Results: 105 trainees spent 361 h on the RoSS. This duration converted to 73 robot-assisted radical prostatectomy cases, and 72 animal lab sessions. RoSS prevented a potential loss of $600,000, while 72 animal labs would have cost more than $ 72,000 without including initial robot installation, annual maintenance and personnel expenses. The mechanical durability testing determined breakdown at 180 and 360 h for master control and pinch device, which were repaired under warranty.
Conclusion: RoSS is a cost effective surgical simulator for implementation of a simulation-based robot-assisted surgical training program.

1. Introduction

The advent of 21st century witnessed an exponential growth in the field of minimally invasive surgery. This holds true for robot-assisted surgery, which has completely revolutionized the way some major oncological procedures are performed. While this change in surgical expertise improved patient related surgical outcomes, it also increased the burden on training standards to develop safe and competent robotic surgeons.[1] Current surgical training environments provide limited operative experience due to work hour limitations, ethical issues and cost restrictions.[2]

Surgical training simulators represent an effective addition to workplace training and help reduce learning curve in a forgiving environment away from the patients.[3] Virtual reality simulators allow for graded practice with objective performance reporting in a safe and familiar environment.[4] Despite these benefits, simulation-based training may restrict the trainee in developing surgical skills because of the lack of tactile feedback, which is pertinent to the 'feel' of human tissue. The realism of any simulation platform helps address this issue and is considered to be an important evaluation parameter before considering it to be an ideal instrument for training. Other important properties of an ideal simulator include an established validity, reliability, educational impact and more importantly cost effectiveness.[5] A recent systematic review on robotic surgical simulators concluded that although most of the simulators have attained the much desired standards of an ideal simulator, however cost effectiveness still remains to be elaborated upon.[6]

Advances in incorporating robotic assisted surgical procedures and warm-up in training by using augmented reality based mentored procedures will lead to more opportunity to practice in low volume centers. However, simulation-based training modalities such as virtual reality (VR) based training is likely to create additional costs for the training center and healthcare system overall. Therefore, establishment of a robotic simulation training program

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requires careful and judicious analysis of available surgical simulators and their cost effectiveness. Recently, Lallas et al. compared the costs of the available virtual reality simulators for robot-assisted surgical training.[7] They reported a comparative analysis of initial expenses associated with the purchase of all available simulators for robot-assisted surgery. However, this group could not determine the indirect savings or their impact with appropriate use of these simulators.

Khan et al. have demonstrated usefulness and effectiveness of simulation for technical and non-technical skills using a centralized simulation model.[8] However, the impact of establishing training programs with high-fidelity virtual reality simulators needs to be analyzed to understand and estimate their cost on the health care system.

This study aims at determining the indirect cost effectiveness of the Robotic Surgical Simulator (RoSS) at Roswell Park Cancer Institute (RPCI) over a period of one year (Fig. 1). Main objectives of this study include: (1) the analysis of the financial impact in comparison with direct training on the robot and its effect on loss of operative time to the institution. Analysis of animal lab expenses is also presented in detail to establish overall costs of training; and (2) evaluation of the durability of the surgical simulator by assessing the breakdown frequency and costs to cover this breakdown and report the overall cost effectiveness of RoSS.

2. Methods

2.1. Study design and settings

This is a retrospective analysis of a prospectively maintained log of training session at the RPCI Center for Robotic Surgery over a period of 12 months (June 2010 to June 2011). Trainees were assigned 1–2 weeks of simulation-based robotic training to complete the RoSS curriculum followed by dry-lab da Vinci robot training and a porcine lab when available (Box 1). Twenty-five trained open/laparoscopic surgeons and 80 trainees (medical students, residents, and fellows) from 11 countries were included in this study. The complete time spent on the RoSS console, dry and wet labs was queried from the training log. Trainees who could not complete the training programme were excluded from the study.

We hypothesized in this study that if training was performed using the operating room (OR) robot, it would have resulted in loss of OR time. This has healthcare as well as financial implications to the institution. With the availability of RoSS, which does not utilize the OR robot for imparting training, the institution had indirect saving of the OR time that would have been lost otherwise. In order to develop a clear understanding of this indirect cost saving the overall training time spent on (RoSS) console was calculated from the training log (record of the training time spent by the participants) and converted to equal time on robotic console for training. This 'saved' time was computed as the total number of most common robot-assisted case (robot-assisted radical prostatectomy). Descriptive analysis of cost was performed to determine the overall costs of training performed on the robotic simulator. Main outcomes of the study included the determination of cost effectiveness and durability of the RoSS (Fig. 2).

Box 1
An over-view of Robotic Surgical Simulator (RoSS)

- RoSS is a validated VR simulator for the daVinci Surgical System that provides an immersive interface by replicating the actual robotic surgical system.
- RoSS reproduces the feel and visualization of the da Vinci Surgical System while incorporating a graduated curriculum that allows trainees to progress from basic orientation tasks to more complex robotic surgical skills tasks.
- The ease of mobility allows RoSS to be located at easily accessible areas. It has undergone face and content validation and is considered as an appropriate tool to learn and evaluate robotic skills prior to real robotic console exposure in the operating room[a,b]
- Validation of a newly developed training curriculum was recently performed and is currently being implemented at Roswell Park Cancer Institute[c]
- At present, RoSS is the only simulator to offer procedure-based modules.
- Hands- on Surgical Training (HoST) technology guides a trainee through the steps of a procedure by moving the console arms and pinch devices in concert with the real robotic console surgeon.

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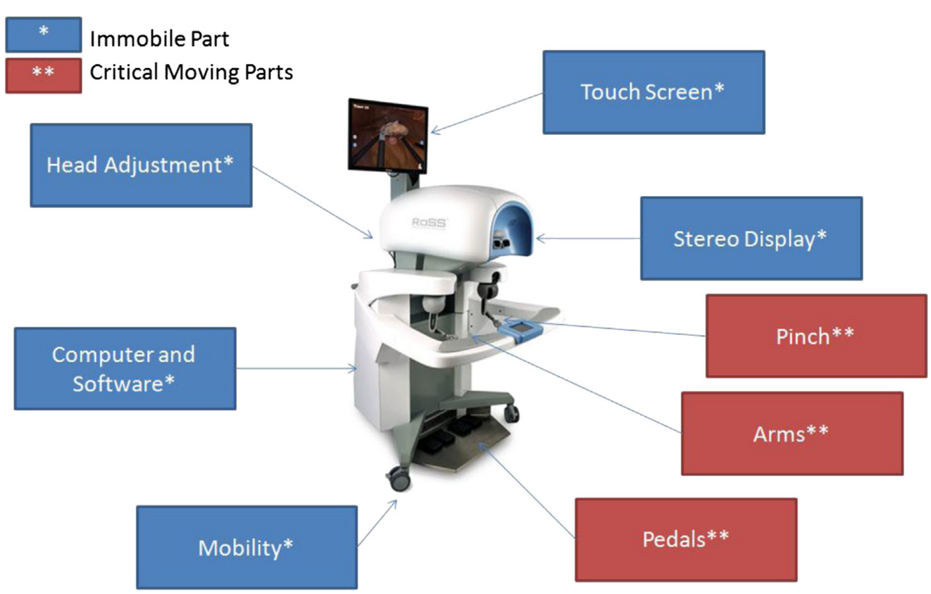

Fig. 1. Diagram depicting components of the Robotic Surgical Simulator (RoSS).

2.2. Cost analysis

Cost analysis was performed by the Department of Financial Services and Surgical Services Administration at RPCI utilizing the highest volume robotic service (Urology) at 65% of total robotic procedures CY 2011. The analysis reviewed the most common robot-assisted surgical procedure (robot-assisted radical prostatectomy) providing a sample size of 190 procedures. This procedure has the highest volume and has been performed for the longest on the robotic equipment at RPCI (2005-present. The number of console hours trainees spent on RoSS were calculated from the training program database and compared with a possible equivalent amount of time in the operating room using the da Vinci Surgical System. Cost analysis compared the utilization of a training laboratory equipped with a simulator and including the initial investment cost, versus an operating room training environment with the da Vinci surgical console. Hypothetically applying the same number of minutes for training during clinical operating time, potential loss of revenue one year was determined. The analysis was limited to the operative encounter only and the overall evaluation did not determine preoperative (non-global) or downstream revenues associated with each patient. Data was provided through the RPCI decision support tool Pin Point and directly from the perioperative best of breed system Surgical Information System (SIS). The cost of a single 5 h animal lab session was also calculated, which included the basic costs of equipment, animal and disposable and non-disposable equipment. A hypothetical cost of animal lab training was also determined for the number of console hours spent on RoSS for training. All unit costs were determined as the money value based on the 2010–2011 financial year and reported in US Dollars ($).

2.3. Simulator durability

Durability was determined by testing the RoSS under artificially created laboratory environment. *Durability was defined as the device breakdown per 100,000 motions*. Input and pinch devices on the RoSS were tested in the virtual reality laboratory at the Department of Mechanical & Aerospace Engineering (University at Buffalo) to determine their durability (Fig. 1). An experimental machine was designed to mechanically move the input devices and simultaneously activate the pinch devices. The system repeated a series of motions 100,000 times to simulate use in the training environment for a period of three years. During the test, position information from the input device and the on-off switch of the pinch device were recorded. Furthermore, a performance log of RoSS utilization at RPCI Center for Robotic Surgery was also analyzed. RoSS has been in use at RPCI since June 2010 and detailed training records and breakdown rates, including concerns reported to the manufacturer, were recorded and evaluated. The manufacturers initially provide 1 year warranty of the simulator and its equipment with its purchase. Any subsequent replacements or repairs to the machine are covered under the annual maintenance cost.

3. Results

3.1. Cost

Urology accounted for 65% of all robot-assisted surgical procedures at RPCI with 190 robot-assisted radical prostatectomies being performed in 2011 by four urologists. The average duration of a robot-assisted radical prostatectomy case was determined to be 296 min, based on the operating room 15-min rates charged to each patient account.

During 2011, the training center at RPCI utilized 361 h (21,608 min) of console time on RoSS. It was calculated that 21,608 min of console time divided by 296 min per procedure (robot-assisted radical prostatectomy) equate to 73 potential

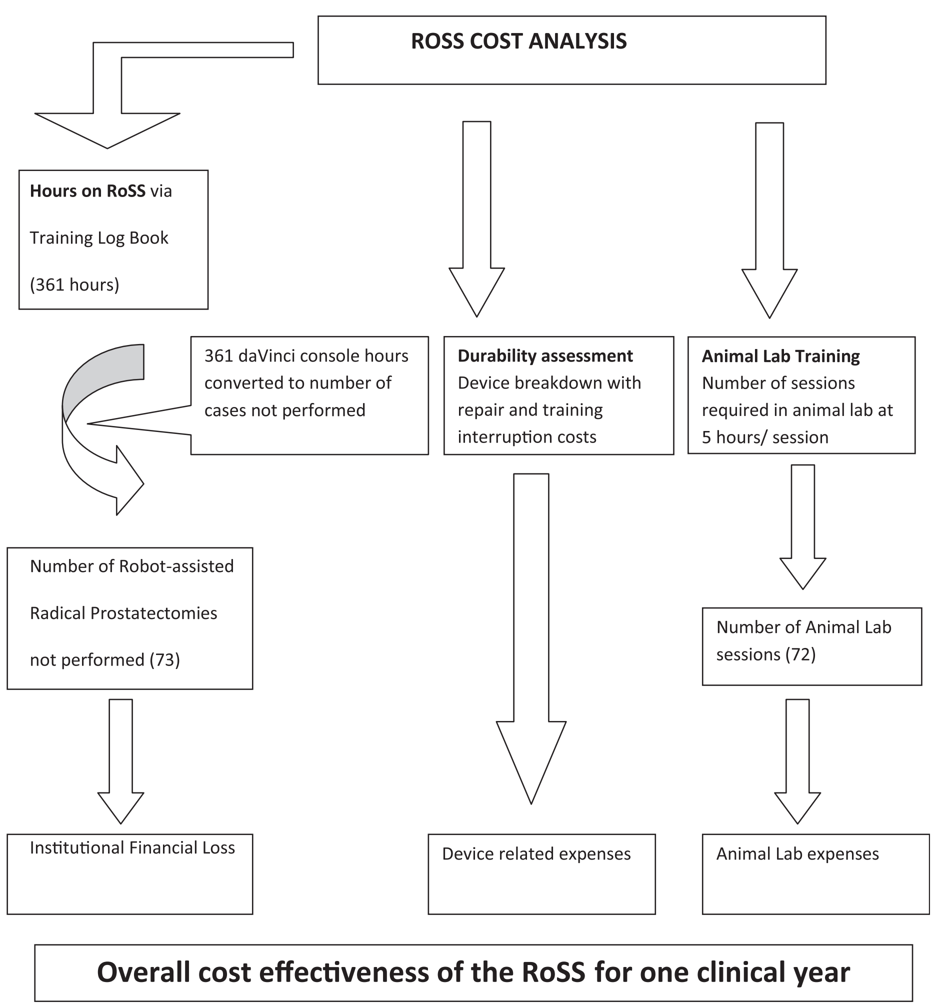

Fig. 2. An over-view of the study.

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patient cases in operating room. Through the utilization of a stand-alone simulator (RoSS) outside the operating room, the organization was able to avoid the loss of 73 patient encounters and operative procedures in patients with localized prostate cancer.

Each patient who underwent a robot-assisted radical prostatectomy had an average hospital stay of 1.5 days. All financial information was evaluated based on the entire patient encounter during the surgical stay, including pathology, radiology and inpatient stay. After direct costs were accounted for, the organization realized an average 25% collection of total charges on the patient accounts, net patient revenue, limited only to technical fees without including professional fees.

In calculating the estimated loss of revenue based in 25% net revenue achievement per patient the organization would have sustained an estimated loss of 38% of annual robot-assisted radical prostatectomy revenue. This was determined by evaluating that if 361 h of operating room utilization was substituted for training endeavors rather than supporting 73 additional cases of robot-assisted radical prostatectomy. The organization would have potential lost opportunity of over one third of total revenue associated with current case volumes. Utilizing the daVinci Surgical System for training would have resulted in potential loss of $622,784.90 in net patient revenue before accounting for the purchase cost of equipment, disposables or personnel expenditures. In this hypothetical model the RoSS utilization delivered five times its cost and avoided potential revenue loss for the organization due to training (Table 1).

The comparison of cost analysis of establishment and maintenance of a robotic simulation training programme is presented in Table 3. The comparative details highlight the cost effectiveness of the RoSS (Table 3). Analysis of direct costs associated with porcine labs at our institution determined a per lab cost of $1093.40 without accounting for veterinarian, technician, and surgical educator personnel expenditures (Table 4). Based on a 5 h single session in the animal tab, the 361 h of RoSS training equated about 72 such sessions for training, thus the overall basic cost of training to be about $79,000. This cost estimate does not include the cost of the robot, its annual maintenance and the professional fees of the above mentioned personnel. Summary of the cost estimation according to the training modality is highlighted in Table 5.

3.2. Durability

The repeated fatigue study revealed that the input devices successfully completed all 100,000 motions without producing any error. Similarly, the pinch devices completed the repeated activation cycle without any error. The input devices on the RoSS system at RPCI were replaced twice and the pinch devices were replaced once during the 2011 calendar year. No problems were encountered with the touch screen display, 3D monitor, or foot pedals. We calculated that breakdown occurred every 120 h of use (Table 2). Only one day was lost to repair over the year; however it did not adversely impact the training program. All maintenance and replacement parts were covered under warranty.

Table 1
Impact of RoSS at RPCI.

Variable	Metric
Prostatectomies performed in 2011	190 cases
Average operative time	296 min
RoSS console hours in 2011	361 h
Potential prostatectomy volume loss	73 cases
Potential OR minute loss	21,608 min
Potential revenue loss	$622,784.90 (38%)
Reimbursement to charges (%)	46%

Table 2
Durability data on RoSS (2011).

Components	Number of problems reported in the year 2011	Durability	Resolution
Computer	0	100%	
Master control	2	2 problems every 360 h of use	Replaced under manufacturer warranty
Pinch device	1	1 problem every 360 h of use	Replaced with redesigned pinch device
Foot pedals	0	100%	
Touch screen	0	100%	
Head adjustment	0	100%	
3-D display	0	100%	

4. Discussion

Robot-assisted surgery has achieved global integration and acceptance over the last decade. Robot-assisted radical prostatectomy volume has increased from 1% of all prostatectomies performed in the United States in 2001 to over 50% of all prostatectomies performed in 2009.[9] Rapid convalescence decreased post-operative pain, reduced intra-operative blood loss, and improved ergonomics have led to its rapid and wide acceptance. Other technical advantages of the da Vinci Surgical System include 3-dimensional visualization, magnification of the operative field, tremor reduction, and range of motions that approximate the human wrist.

However, a different set of skills is needed to master the human–machine interface of a robotic surgical system. Before a surgeon-in-training can perform robot-assisted surgery on a patient, basic surgical skills are needed to be mastered. According to the Society of American Gastrointestinal and Endoscopic Surgeons (SAGES) and the Minimally Invasive Robotic Association (MIRA) Robotic Surgery Consensus Group, it is essential to complete a course in practical education in therapeutic robotics.[10] This provides necessary skill training and familiarization with the surgical technology prior to the initiation of a mentored clinical experience. However, the high initial cost of purchasing and maintaining the robotic surgical system and potential loss of operating room time may deter academic institutions from successful implementation of a robotic surgery training program.

The ethics involved in training on patients and compulsions to reduce medical errors have added to these constraints. Training with animals offers a viable and safer alternative, but carries considerable cost. Equipment expenditures of a da Vinci surgical system for training is cost prohibitive, even if a surgical robot and other miscellaneous technical equipment are accessible. Virtual reality simulation for robot-assisted surgical training may offer a constructive and economical alternative to overcome patient safety and costly animal training constraints.[11] Berry et al. demonstrated a cost ratio of 0.74 in favor of virtual reality laboratory training over animal training.[12] At least four different surgical simulators are presently available on the market to train surgeons in the fundamentals of robot-assisted surgery, including RoSS.[6]

Table 3
Expenditures to establish training program.

Platform	Cost	Annual maintenance
Robotic Surgical Simulator (RoSS)	$125,000.00	$12,500.00
daVinci Surgical System Si		
Single console	$1,750,000.00	$150,000.00
Dual console	$2,250,000.00	$150,000.00

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Table 4
Direct Cost of Porcine Lab (without robot and personnel expenses).

Item	Per lab cost
Animal	$280.00
Operating room utilization fee	$300.00
Robotic instruments	
Large Needle Driver (2)	$110.00
Monopolar Curved Scissors (1)	$80.00
Maryland Bipolar Forceps (1)	$67.50
ProGrasp Forceps (1)	$55.00
Disposable misc. surgical supplies	$154.16
Reuseable misc. surgical supplies	$46.74
Total	$1093.40

In a study by Schroeck et al., trainees did not negatively affect the blood loss and surgical margin rates of robot-assisted prostatectomy in a structured training program.[13] The financial impact related to utilizing RoSS for training as analyzed in this article revealed a positive return on investment based on preservation of operating room time and robotic equipment. The robot-assisted surgical training program at RPCI uses RoSS for inanimate simulation and also offers dry lab training on a da Vinci robot as well as provision for a porcine wet lab. This structured training is more effective for training and improving performance at the surgical console. Kesavadas et al. demonstrated that training on RoSS was shown to significantly reduce the time taken to complete tasks on da Vinci Surgical System.[14] In a study by Frost and Sullivan on the laparoscopy AccuTouch system, cost savings in excess of $160,000 were realized based on quicker completion times with reduced errors, instructor time savings and avoidance of equipment spoilage costs.[15] In another study, Steinberg et al. showed that robot-assisted radical prostatectomy operative costs are directly related to the length of the learning curve ranging from $95,000 to $1,365,000. This resulted in an additional $217,000 worth of operative time per year during a trainee's learning curve.[16]

Utilization of a simulation-based robotic surgical training program can improve the learning curve and lead to cost reduction in robotic surgeries based on operative times. Our study demonstrates, through the utilization of a stand-alone simulator, loss of care for 73 prostate cancer patients (patient encounters and operative procedures) was avoided.

Durability is a critical issue for continued use of simulators as part of surgical training curriculum. Trainees often have limited time and break down of the simulator can have a substantially negative impact on a training program. In a multi-institutional questionnaire review of the da Vinci Surgical System, malfunction was observed to be extremely rare with only 0.4% of all fault errors determined to be non-recoverable.[17] On the other hand, Korets et al. reported that their simulator, the Mimic dVTrainer (MdVT), required repairs every 22 h of use.[18] This resulted in repair related delays of 3 and 7 days for gimbal malfunction and stereoscope failure, respectively. Experience with RoSS during our study, showed breakdown occurrance once every 120 h of use with a waiting period of one day for repair. Further mechanical testing showed that input devices and pinchers were capable of providing unhindered use for up to three years in experimental settings. Manufacturers of simulators must focus on durability as it becomes closely integrated into the robot-assisted surgical training and additional funding to support such ventures is hard to obtain. Simulator such as RoSS may benefit basic surgical training for safety during early surgical career development. Keeping in view the economic burden of the health care optimum utilization of such training devices will allow safety, access and opportunity to optimize a robot-assisted surgical program.

Table 5
Comparison of the training modalities.

Training modality	Establishment cost	Annual maintenance	Cost of 361 h	Grand total
RoSS	$125,000.00	–	–	$125,000.00
OR Robotic Console (Robotic Prostatectomies not done)	$1,750,000.00	$150,000.00	$622,784.90	$2,522,784.90
Animal Lab Sessions	$1,750,000.00	$150,000.00	$78,943.40	$1,978,943.00

This article has a few limitations. An analytical study of additional cost savings was not a part of this analysis and is scheduled for further evaluation. It would be achieved by an improved ability of trainees to safely complete procedures in a timely fashion and optimize their utilization of the robotic surgical system in the operating room. A formal robot-assisted surgical training program can aid in this endeavor by allowing more trainees to learn without sacrificing the operating room time and capacity for patient care. The results of this study reflect a single institution, single procedure-based costs, which may compromise its generalized applicability to other centers. The variations in training activities are also a limitation to these results and limit its application across other centers. No direct cost comparison was performed between various available robotic surgery simulators in this study. In the future, cost and durability of such simulators should be determined by simultaneous use in a single training institute or through a prospective multi-institutional study.

5. Conclusions

RoSS is a cost effective surgical simulator for implementation of a robot-assisted surgical training program with foreseeable benefit of reducing the cost of surgical education.

Ethical approval

None.

Funding

None.

Author contribution

Shabnam Rehman: Study Design
Syed Johar Raza: Study Design, Writing
Andrew P. Stegemann: Study Design, Data Collection
Kevin Zeeck: Data Collection
Rakeeba Din: Data Collection
Amanda Llewellyn: Study Design
Lynn Dio: Data Collection
Michael Trznadel: Data Collection
Yong Won Seo: Data Collections, Analysis
Ashirwad J. Chowriappa: Study Design, Writing
Thenkurussi Kesavadas: Writing
Kamran Ahmed: Data Analysis, Writing
Khurshid A. Guru: Study Design, Data Analysis, Writing

Conflict of interest

Khurshid Ahad Guru and Thenkurussi Kesavadas are board members of Simulated Surgical Systems LLC.

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