Effectiveness of Laparoscopic Computer Simulator Versus Usage of Box Trainer for Endoscopic Surgery Training of Novices

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OBJECTIVE: Teaching of laparoscopic skills is a challenge in surgical training programs. Because of the highly technical nature and the steep learning curve, students and residents must learn laparoscopic skills before performing them in the operating room. To improve efficiency of learning and patient safety, research in simulation is essential. Two types of simulators currently in use include virtual reality and box trainers. Our study examined which simulator technique was most effective in teaching novice trainees laparoscopic techniques.

DESIGN: This is a prospective, randomized, blinded, controlled trial that enrolled fourth-year medical students and surgical interns to participate in a supervised 6-month laparoscopic training program with either computer simulators or box trainers. Subjects were randomized and trained on appropriate laparoscopic camera skills, instrument handling, object positioning, dissection, ligation, suturing, and knot tying. Students within one group were not allowed to practice, learn or train on the opposing trainers. At time points 0, 2, and 6 months all subjects completed a series of laparoscopic exercises in a live porcine model, which were captured on DVD and scored by blinded expert investigators.

RESULTS: Scores improved overall from the pretest to subsequent tests after training with no difference between the virtual reality and box simulator groups. In the medical students specifically, there was overall improvement, and improvement in the needle-transfer and knot-tying skills specifically, with no difference between the box simulator and virtual reality groups. For the interns, both groups showed significant overall improvement with no difference between the virtual reality and box simulator groups or on individual skills.

CONCLUSIONS: We conclude that laparoscopic simulator training improves surgical skills in novice trainees. We found both the box trainers and the virtual reality simulators are equally effective means of teaching laparoscopic skills to novice learners. (J Surg 68:282-289. © 2011 Association of Program Directors in Surgery. Published by Elsevier Inc. All rights reserved.)

KEY WORDS: simulators, box trainers, virtual reality, laparoscopy, training

COMPETENCIES: Patient Care, Practice-Based Learning and Improvement, and Systems-Based Practice

INTRODUCTION

The exponential growth of minimally invasive surgery has challenged conventional systems for surgical training and establishment of competency. The longstanding dogma of "see one, do one, teach one," is being increasingly challenged by legal and ethical concerns for patient safety issues, malpractice concerns, operating room efficiency, and surgeon efficiency. Perhaps most importantly, it is inhibited by work-hour restrictions that limit resident availability for educational endeavors. The rapid explosion of minimally invasive surgical techniques being applied to more complex operations compounds this issue. Hence, a conundrum of how best to teach technical skills to residents complicates and challenges the current surgical training system.

A large body of evidence suggests that a well-structured curriculum, which incorporates simulated laparoscopic surgical training, improves performance in both the animal laboratory[1-5] and human[6-9] operating rooms. Most of these studies have evaluated surgery residents' training on commercially available laparoscopic simulators, but few have assessed subjects trained on a virtual-reality trainer compared with those trained with a traditional box trainer over a specified time period.[1,2,4,7,9,10] Hence, we propose to determine

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whether training with a laparoscopic computer simulator versus box trainers leads to improved performance of laparoscopic skills in the operating room environment during a 6-month interval, including training and assessment.

New methods of developing and teaching laparoscopic skill sets are necessary because it is becoming increasingly clear that laparoscopic surgery requires a different skill set with manipulation of surgical instruments on a 2-dimensional video screen in an actual 3-dimensional operative field.[11-15] Spatial relationships, psychomotor skills, and the development of ambidextrous skills in a small intra-abdominal space are often a difficult task for novices to perform when learning the principles of minimally invasive surgery.[16,17] With the added restrictions on work hours, teaching residents to perform these advanced laparoscopic procedures proficiently requires them essentially to master some of these techniques before their actual performance in the operating room environment. Learning these skills during medical school could also serve to plateau the learning curve during residency. This may be accomplished with the aid of surgical simulators.

Structured task repetition over several sessions instead of mass training during a single session is an important aspect of motor training that is pivotal to achieving proficient laparoscopic skill acquisition and long-term retention.[18,19] Although this principle has been embraced by many academic centers, more than half of the surgical programs with surgical simulations have mandatory resident attendance.[7,20-25] The number of schools using simulation for medical student training is even fewer. This infers that many programs may not be instituting an ideally structured simulation curriculum. Hence, uniform training and thus mandatory participation can lead to good compliance that can be translated to maximum curricular efficiency.

Both computer simulators and box trainers are being used in the training of surgical residents. Interestingly, it is not known which training vehicle is superior and more cost effective in teaching learners laparoscopic skills. It is also unclear which method equates with better compliance, and more importantly, which method best recapitulates the human operating room environment, which can potentially reduce trainees' errors and make the "see one, do one, teach one" a relic of the past.

We plan to illustrate that a well-structured, timed curriculum that incorporates simulated laparoscopic surgical training improves laparoscopic skill acquisition. Furthermore, we aim to decipher whether a laparoscopic computer simulator or usage of a box trainer leads to better intraoperative laparoscopic skills and a better module for learner education.

MATERIALS AND METHODS

Subjects

Novice fourth-year medical students and surgical interns enrolled voluntarily in an Institutional Review Board (IRB) exempt prospective, randomized, blinded, controlled trial that assigned novice subjects to formal scheduled laparoscopic training with either computer simulators or box trainers. These trainees were randomized to a scheduled training session in a laparoscopic computer simulator laboratory or to a control group (box trainer group) (Fig. 1). Subjects randomized were trained on appropriate laparoscopic camera skills, instrument handling, object positioning, dissection, ligation, suturing, and knot tying over a 6-month interval. Simulator skills were taught in both training arms and mandatory training time was required of each group. Training was geared toward the laparoscopic skill set for the assessment examination. All subjects then completed a series of laparoscopic exercises in a live porcine model, and their performance was assessed independently by blinded reviewers at each interval time period.

Experimental Conditions

All subjects underwent a group orientation to the computer simulator laboratory, box trainers, and the required basic skills tasks: laparoscopic camera navigation, instrument handling, object positioning, dissection, ligation, suturing, and knot tying. Each subject performed a single, supervised practice repetition to orient him or her to the computer simulator and box trainer, respectively. Subjects were required to perform a minimum of 10 repetitions, because a prior study demonstrated that the learning curve for junior surgeons reached a plateau around eight repetitions. Hence, a minimum of 10 repetitions is required to ensure that trainees received adequate training on the simulator exercises.

Subject training occurred over a 6-month period during which a series of laparoscopic skills were assessed at time zero, two, and 6 months. All subjects were oriented to the animate laparoscopic tasks by one of the primary investigators using scripted instructions and demonstration of optimal performance for each task. The tasks included a 30° camera navigation exercise, 2 eye-hand coordination exercises, clipping and electrocautery, and a knot-tying exercise. The 30° camera navigation exercise required the subject to find and focus on 4 "targets" measuring 1 cm in diameter which were placed at various preselected locations within the abdomen. The placement of the "targets" required the subject to use the 30° optics of the laparoscope to locate the objects within the abdomen successfully. The first eye–hand coordination exercise focused on 2-handed transfers. Using 2 laparoscopic graspers, the subject stood at the foot of the pig and transferred a needle with a left-handed grasper from the right lobe of the liver up into the air to be grasped by the right-handed grasper, and then placed gently down on the left lobe of the liver. This procedure was then reversed and repeated 2 times. One of the investigators held the laparoscope for this exercise. The second eye–hand coordination exercise evaluated 1-handed object transfer and 0° camera navigation skills. The subject handled the laparoscope first with his/her left hand and transferred a 1-cm "target" with a grasper in his/her right hand from the right lobe of the liver to the spleen while standing on the pig's left side. This procedure was then reversed with the subject standing on the pig's right side, and he/she was then asked to handle the laparoscope with their right hand while using a grasper

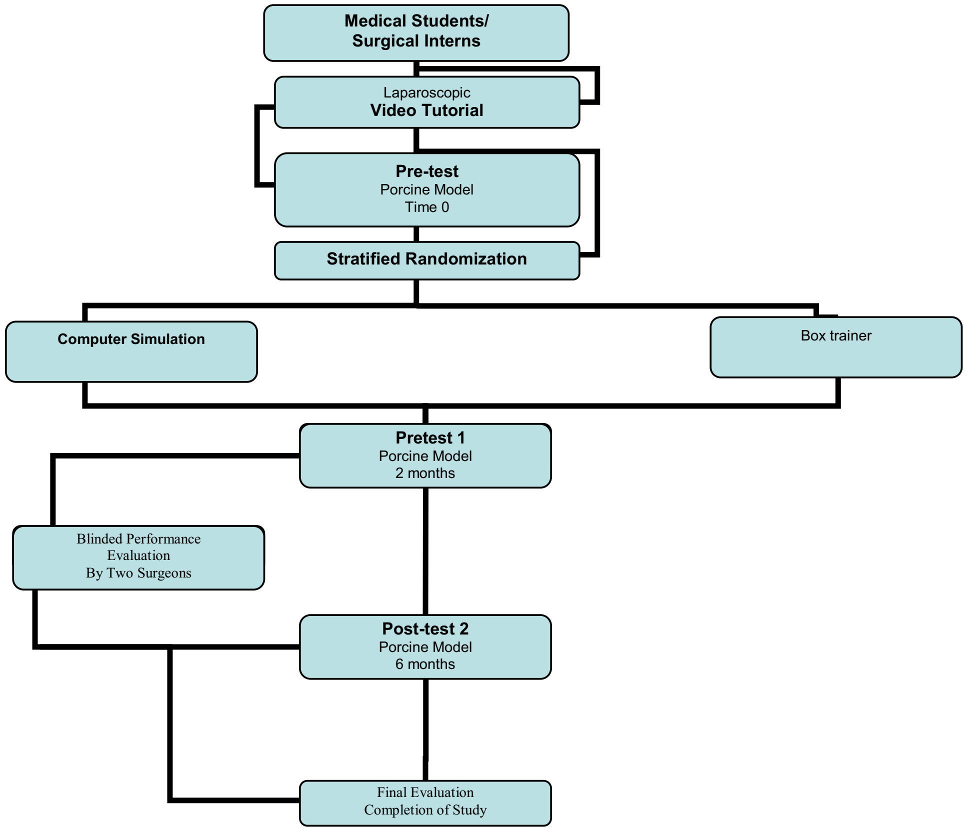

FIGURE 1. Experimental design.

to transfer the "target" from the spleen back to the liver. The subject was to keep the grasper in view at all times during the transfers. Last, a safe clipping and electrocautery exercise was performed. A short segment of bowel was suspended by 2 assistants, and a window was created in the mesentery on either side of a mesenteric vessel. The subject was then asked to handle the laparoscope with his/her left hand and to place 2 clips proximally and 1 distally on the vessel and to divide the vessel between them using electrocautery scissors. Safe clipping and electrocautery techniques were emphasized for this exercise. Last, the subject performed a complete intracorporeal knot with a previously placed suture in the stomach within a 5-minute time limit.

Scoring

Each subjects' performance was captured on DVD and their performance was reviewed by 2 investigators blinded to the training status and identity of the subject (Fig. 2). Each task was viewed separately by the reviewers for all subjects. This allowed for focused evaluation of a specific skill set for all subjects, rather than viewing the entire porcine laboratory performance for 1 subject at a time. The porcine model was chosen as it recapitulates closely the human operating room environment and allows utilization of the same laparoscopic instrumentation and equipment used in our hospital, thereby creating a realistic intraoperative environment.

Local/Institution Review Board

We obtained approval from Duke University Institutional Animal Care and Use Committee Protocol for Teaching Endosurgical Techniques in a nonsurvival porcine model and for a project examining laparoscopic skill acquisition in interns/medical students using different laparoscopic simulators. We received an IRB exemption because this was a voluntary educational project and the outcomes were recorded anonymously.

Statistical Analysis

All statistical analyses evaluating the efficacy of the 2 interventions were measured with 95% confidence intervals. An analysis was initiated by evaluating the distribution of all variables using means/standard deviation and frequency/percentages. Although all efforts were made to avoid missing values, given the small number of subjects, missing values can play an important role in the study. If a subject did not have a baseline time point, they were not included in the study. If a subject had only 1 of

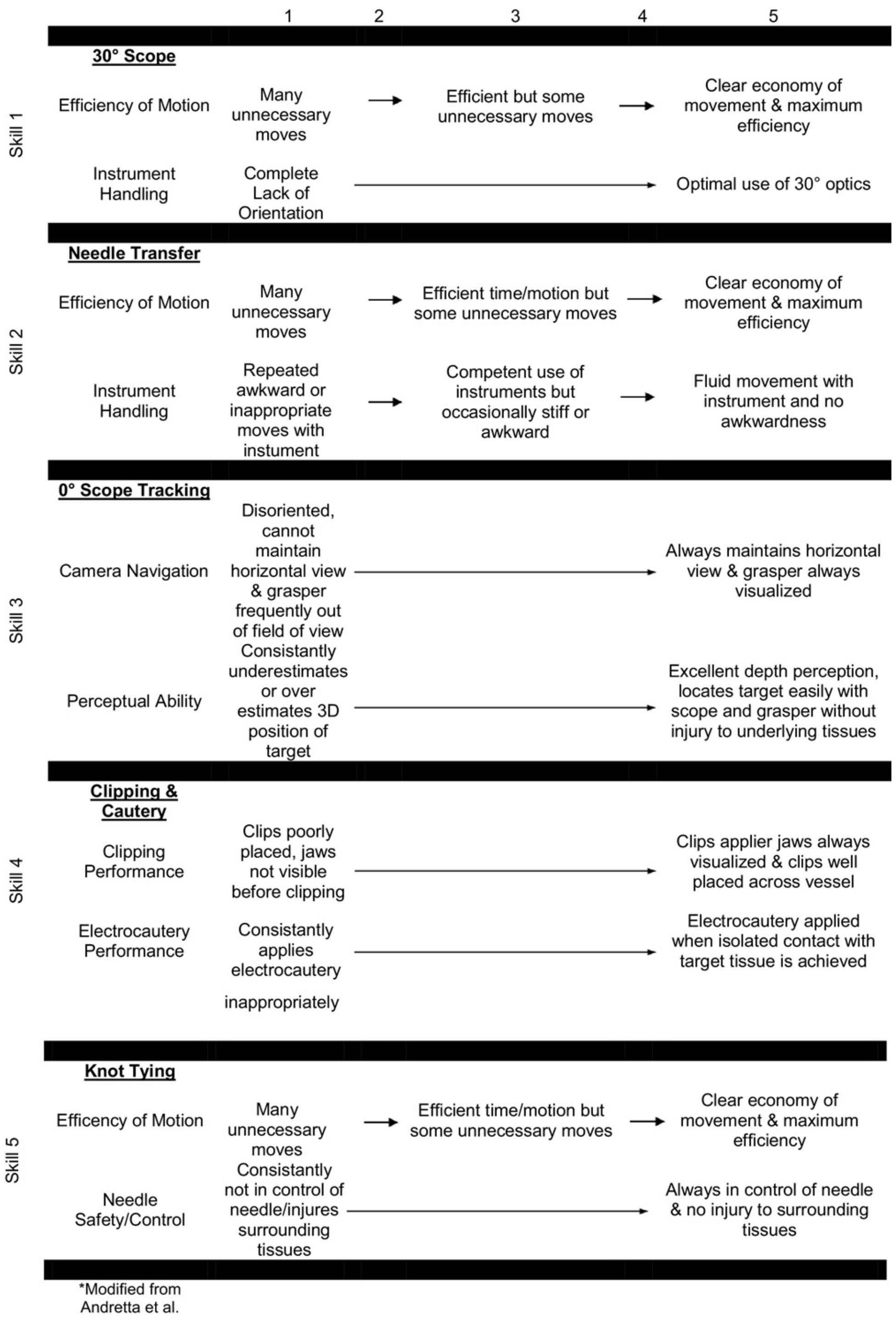

FIGURE 2. Scoring system.

the 2 time points (2 months or 6 months), the available time point was used. Subjects with only 1 time point available were not used.

Each skill had 2 scores of performance. The composite score was a combination of both of these individual scores with a minimum of 2 and a maximum score of 10. A bivariate analysis initially evaluated confounding of all variables in the association between training method and the surgical dexterity scale. If a confounding variable was judged to be present, then models were used to adjust the association between dependent and independent variables. Otherwise, a bivariate analysis was used to evaluate the efficacy of the training intervention.

TABLE 1. Performance of All Groups

	Overall		Box	Virtual	
	Overall	p	Team 1 Rank Sum (observed)	Team 2 Rank Sum (observed)	p
Skill1_1 30 degree scope Efficiency of motion	Equivalent	0.064	70.0 (8)	101.0 (10)	0.593
Skill1_2 30 degree scope Instrument handling	Equivalent	0.256	67.0 (8)	104.0 (10)	0.422
Skill2_1 Needle transfer Efficiency of motion	Improved	0.0002	65.5 (8)	105.5 (10)	0.349
Skill2_2 Needle transfer Instrument handling	Improved	0.0002	60.0 (8)	111.00 (10)	0.152
Skill3_1 0 degree scope tracking Camera navigation	Improved	0.006	86.5 (8)	84.5 (10)	0.348
Skill3_2 0 degree scope tracking Perceptual ability	Improved	0.0495	79.5 (8)	91.50 (10)	0.755
Skill4_1 Clipping and cautery Clipping performance	Equivalent	0.256	51.5 (7)	101.5 (10)	0.261
Skill4_2 Clipping and cautery Electrocautery performance	Improved	0.037	62.5 (7)	90.5 (10)	0.961
Skill5_1 Knot tying Efficiency of motion	Improved	0.010	77.0 (8)	94.0 (10)	0.929
Skill5_2 Knot tying Needle safety/control	Equivalent	0.032	71.0 (8)	100.0 (10)	0.656

RESULTS

Demographic Data

In total, there were 11 surgical interns and 12 medical students who participated in this study for a total of 23 participants;18 of the 23 completed at least 2 of the 3 porcine evaluations. The male-to-female ratio was 13:10 with the gender ratio of medical students being 6:6 and the ratio of the interns being 7:4. Most of the medical students reported some previous video gaming experience with 4 reporting they own video game players and play whenever they have time. All the participants were novices with no significant laparoscopic experience and little (1 to 2 sessions) to no previous simulator time.

Performance of Total Group

Scores improved overall from the pretest to subsequent tests after training. This improvement was statistically significant overall. The skills assessed included laparoscopic camera skills 30° (skill 1), instrument handling (skill 2), object positioning and camera orientation (skill 3), dissection/ ligation (skill 4), and knot tying (skill 5) at times 0, 2, and 6 months from the start of the study. Each skill had 2 separate assessments. Individual skills that improved over time included needle transfer efficiency of motion, needle transfer instrument handling, 0° score tracking camera navigation, 0° scope perceptual ability, electrocautery performance, efficiency of knot tying, and knot tying needle safety and control (Table 1). When the subsections of the skills were combined to composite skill scores, none of the composite skill scores were significant. No difference was found between the average score of the box simulator participants verses the virtual reality simulators participants overall or with respect to any individual skill (Table 1).

Performance of Medical Students

An overall improvement in scores was found from the pretest to subsequent tests after training ($p < 0.006$, Table 2). This improvement was statistically significant overall and specifically in the needle-transfer skill and knot-tying skill, which was the most technically challenging of the skills for the learners. No difference was found between the average score of the box simulator participants versus the virtual reality simulators participants, regardless of the skill. In short, the virtual reality group

TABLE 2. Performance of the Medical Students

Table A	Time 0 (Pretest)	Month 2	Month 6	p
Overall	2.79	3.25	3.28	0.006
Skill 1 30° scope	3.06	3.25	2.86	0.395
Skill 2 Needle transfer	2.12	3.15	3.39	0.001
Skill 3 0° scope	3.03	3.42	3.20	0.354
Skill 4 Clipping and cautery Electrocautery	3.37	3.66	3.86	0.079
Skill 5 Knot tying	2.34	2.74	3.10	0.024

tended to be better (on all but skill 3) but the largest difference between the groups is only 0.68, which we were not powered to detect.

Performance of Interns

Both groups showed significant overall improvement in all skills at 6 months compared with 0 months. No significant difference was detected between the groups at any of the time points 0, 2, or 6 months ($p = 0.78$, 0.48, and 0.64, respectively). Composite scores increased from 4.50 to 6.98 ($p = 0.04$) in the box trainer group and from 4.72 to 6.55 ($p = 0.02$) in the VR group. Resident participation was limited because of perceived clinical duties so conclusions were based on mean scores of active participants at each time point.

Performance of Medical Students Versus Interns

When comparing the medical students and interns, no significant difference was found between the performance of the medical student and the interns for any of the total skill scores. When examining the both assessments for each skill, the interns were better at electrocautery performance ($p < 0.01$), but there was no significant difference on any other skill.

DISCUSSION

This study was a prospective, randomized, blinded, and controlled trial that enrolled novice subjects to formal scheduled laparoscopic training with either virtual reality simulators or box trainers. Training sessions in the 2 groups covered similar skills and a similar mandatory number of training repetitions. All subjects completed the same series of laparoscopic exercises in a live porcine model, and blinded reviewers assessed their performance independently at each specified time interval. The porcine model was chosen as it recapitulates closely operating on actual patients and allows use of the same laparoscopic instrumentation and equipment used in our hospital, thereby creating a realistic intraoperative environment.

Our results demonstrate that overall, a structured laparoscopic training course improves laparoscopic skills in novice trainees. This was true in both the virtual reality as well as the box simulator groups. Historically, virtual reality surgical simulators were conceived from previous experiences of inanimate training and aviation simulators. The notion is to create a "realistic" operating environment that offers unlimited laparoscopic practice without detrimental consequences when trainees make mistakes. With the development of haptic virtual simulator based on the science of "the study of sensing through touch," these new simulators have provided an immersive environment for surgeons to touch, feel, and manipulate computer-generated 3-dimensional tissues and organs with tool handles used in actual operating theaters. Such simulators have enabled us to standardize the assessment of surgical skills and avert the need for cadavers and animals currently used in training.

Medical Education Technologies, Inc. (Sarasota, Florida) has developed a laparoscopic surgical simulator for surgical education with an expandable surgical platform that includes life-like surgical anatomy and the ability to record the learner's performance during each session; in addition, it offers an immediate review and critique of the performed laparoscopic skill. This allows surgeon-trainees to develop and test their technical, cognitive, and medical decision-making skills in a safe virtual environment. Immersion (San Jose, California) has developed a laparoscopic surgical simulator with state-of-the-art haptic feedback to take this simulation training 1 step closer to a true simulating operative experience. Both of these were used in our virtual reality group training.

Less elaborative box trainers, such as Surgi Trainer (U.S. Surgical Corporation, Norwalk, Connecticut) or Stryker equipment towers (Stryker, Kalamazoo, Michigan) use laparoscopic surgical instruments and equipment, and they are used frequently to train novice surgical residents on basic laparoscopic skills. This equipment video monitoring, laparoscopes, and a variety of laparoscopic graspers and needle drivers. Often, these use an opaque box that attempts to depict the size of an adult human abdominal cavity, with prefabricated anterior slits through which trocars (access ports) and laparoscopic instruments may be placed and manipulated all while viewing this on a video monitor. This allows a simple, low-cost simulated laparoscopic experience, development, and practice of minimally invasive surgical skill sets. These trainers can also be used with the same instruments used in the local operating rooms.

The choice of the most efficient training simulator is an important decision for surgical residency programs. The cost of the trainers, annual maintenance, and support staff needed varies based on the type of simulator. The cost of box simulators per unit ranges from $1500 to $10,000. Virtual reality trainers vary from $40,000 to $150,000 with the simulator in this study costing approximately $50,000 per unit. Overall, box trainers require more materials and staff support for training with approximately $250 in materials per year per trainee, whereas virtual reality trainers require software updates and computer support. For the trainees, at least 2 hours are required for box trainer orientation, while 1 hour is required for virtual reality simulators. This may be done in groups or individually. Trainers' time is usually part of teaching responsibility of faculty, whereas certain complex virtual reality simulators do require dedicated trainers. These costs may be decreased with discounts or donations of materials, but overall, virtual reality trainers cost substantially more than box trainers. Many programs, such as ours, incorporate both box trainers and virtual reality simulators in the training of surgical residents. Future studies, including a combination of training modalities may also be helpful to determine whether using both simulators is better than either individual simulator alone.

Our results confirm earlier reports that medical simulators enhance learning in trainees especially when trainees practice with progressively more difficult simulations.[26-29] Since the institution of simulation, there has been the question of which modality most efficiently and effectively leads to skills acquisition. We found both the box-trainers and the virtual reality simulators are equally effective means of teaching laparoscopic skills to novice learners (Tables 1 and 2). We could not detect improved performance for 1 simulator over the other when evaluating the group overall, within groups, or within specific skill sets (Tables 1 and 2). With the significant cost associated with current virtual reality simulators, the use of box trainers might be an effective, economic alternative for surgical residency programs. However, effective training in a box simulator requires supervision.

By contrast, newer virtual reality simulators with improved haptics, better metrics, and an improved simulated environment may make a difference not realized in this study because of the small sample size. New simulator software is available that was not tested in our resident population. Improved simulator software would allow more complex scenarios and a greater variety of simulation for the trainee. Interactive simulation also allows more independent training. Although not assessed in this study, the variety of simulation provided by the virtual reality simulator may improve resident compliance or interest in simulation compared with the traditional box simulator. As the software continues to improve and fidelity continues to increase, conceptually one should be able to improve operative skill.

An important aspect to education apparent during this study was the need for protected educational time. To benefit from simulator training, surgical residents need dedicated time to participate in training exercises. With the implementation of the 80-hour workweek, self-motivated study is limited in off hours. This was particularly apparent with the interns in this study. Protected proctored simulator time provides the most realistic opportunity for students and residents to acquire laparoscopic skills outside of the operating room.

This study established a proficiency-based laparoscopic curriculum for medical students and interns using a simulation system and inanimate models, which validates transferability of this curriculum to the operating room. It allowed us to determine that both previously validated laparoscopic video trainers and simple box trainers increased curriculum efficiency. The laparoscopic program we developed will enable us to train novice surgeons proficiently, from medical students through surgery residents to maximize their efficiency and effectiveness, minimize cost, and ensure patient safety by optimizing learning curves.

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