Journal of Surgical Research 156, 312–316 (2009)
doi:10.1016/j.jss.2009.04.018

The Role of Haptic Feedback in Laparoscopic Simulation Training

Lucian Panait, M.D.,* Ehab Akkary, M.D.,† Robert L. Bell, M.D.,† Kurt E. Roberts, M.D.,† Stanley J. Dudrick, M.D.,*,† and Andrew J. Duffy, M.D.†,[1]

*Saint Mary's Hospital, Waterbury, Connecticut; and †Yale School of Medicine, New Haven, Connecticut

Submitted for publication January 9, 2009

Introduction. **Laparoscopic virtual reality simulators are becoming a ubiquitous tool in resident training and assessment. These devices provide the operator with various levels of realism, including haptic (or force) feedback. However, this feature adds significantly to the cost of the devices, and limited data exist assessing the value of haptics in skill acquisition and development. Utilizing the Laparoscopy VR (Immersion Medical, Gaithersburg, MD), we hypothesized that the incorporation of force feedback in the simulated operative environment would allow superior trainee performance compared with performance of the same basic skills tasks in a non-haptic model.**

Methods. **Ten medical students with minimal laparoscopic experience and similar baseline skill levels as proven by performance of two fundamentals of laparoscopic surgery (FLS) tasks (peg transfer and cutting drills) voluntarily participated in the study. Each performed two tasks, analogous to the FLS drills, on the Laparoscopy VR at 3 levels of difficulty, based on the established settings of the manufacturer. After achieving familiarity with the device and tasks, the students completed the drills both with and without force feedback. Data on completion time, instrument path length, right and left hand errors, and grasping tension were analyzed. The scores in the haptic-enhanced simulation environment were compared with the scores in the non-haptic model and analyzed utilizing Student's *t*-test.**

Results. **The peg transfer drill showed no difference in performance between the haptic and non-haptic simulations for all metrics at all three levels of difficulty. For the more complex cutting exercise, the time to complete the tasks was significantly shorter when force feedback was provided, at all levels of difficulty (158 ± 56 *versus* 187 ± 51 s, 176 ± 49 *versus* 222 ± 68 s, and 275 ± 76 *versus* 422 ± 220 s, at levels 1, 2, and 3, respectively, $P < 0.05$). Data on instrument path length, grasping tension, and errors showed a trend toward a benefit from haptics at all difficulty levels, but this difference did not achieve statistical significance.**

Conclusions. **In the more advanced tasks, haptics allowed superior precision, resulting in faster completion of tasks and a trend toward fewer technical errors. In the more basic tasks, haptic-enhanced simulation did not demonstrate an appreciable performance improvement among our trainees. These data suggest that the additional expense of haptic-enhanced laparoscopic simulators may be justified for advanced skill development in surgical trainees as simulator technology continues to improve.**

Key Words: **virtual reality; surgical simulation; force feedback; haptic.**

INTRODUCTION

Laparoscopic virtual reality simulators are becoming a ubiquitous tool in resident training and assessment. These devices provide various levels of realism, including haptic (or force) feedback. The cost of these useful training tools is a significant deterrent to their acquisition for many programs, and the presence of force feedback adds significantly to the expense. Laparoscopy VR (Immersion Medical, Gaithersburg, MD) is a new generation of haptic-enhanced virtual reality simulator, which offers basic skills similar to the FLS drills, as well as full procedure simulation. The tasks preinstalled in the device can be adjusted over a wide range of scenarios to help focus the training experience. The simulator software also tracks multiple relevant

[1] To whom correspondence and reprint requests should be addressed at Yale School of Medicine, Section of Gastrointestinal Surgery, 40 Temple Street, Suite 7B, New Haven, CT 06510. E-mail: Andrew.Duffy@yale.edu.

0022-4804/09 $36.00

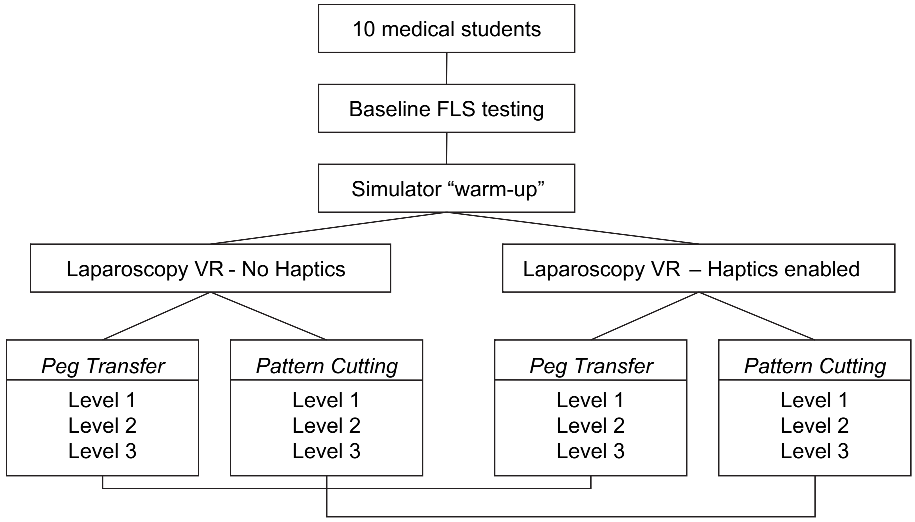

FIG. 1. Study outline.

performance metrics, including time to perform tasks, instrument path length, dexterity, missed objects, tissue damage, and grasping tension. Previous work demonstrated that performance on the Laparoscopy VR simulator correlated with surgical skill level as measured by two basic FLS tasks [1].

Limited data exist assessing the value of haptics in skill development. Utilizing the Laparoscopy VR, we hypothesized that the presence of force feedback in the simulated environment would allow superior trainee performance compared with performance of the same basic skills tasks in a non-haptic model.

METHODS

Laparoscopy VR software contains modules for simulating essential laparoscopic skills, as well as full procedural skills. The essential skill modules are designed to resemble the FLS drills, and each has three preset levels of difficulty. For the purposes of our study, only the Peg Transfer and Pattern Cutting drills were utilized.

Ten medical students with minimal laparoscopic experience voluntarily participated in the study. All students were right-handed. They were evaluated initially for baseline skills using two FLS tasks (Peg Transfer and Pattern Cutting), with calculation of the FLS score in standard fashion, based on performance time and errors. The participants were then allowed to achieve familiarity with the virtual reality device and drills, in order to avoid differences in performance related to software design or unease with the instruments. One week after the initial simulator "warm-up", each student performed two tasks, analogous to the FLS drills, on the Laparoscopy VR at three levels of difficulty. The levels are based on the manufacturer established settings, and were not modified at all by the authors. The same drills were completed both with and without force feedback (Fig. 1). The students performed the drills in the non-haptic simulation environment first, and then in the haptic-enhanced environment. However, in order to avoid the effect of learning curve by performing the tasks one after the other, at least 2 h were allowed to pass from completion of the drills in the non-haptic simulation to the start of the haptic-enhanced drills.

In the Peg Transfer drill, the students were required to use a grasper in order to pick up a peg from the simulated tissue and place it into a specific hole on a board. Pegs were picked up alternatively with the right and left hand until the assigned task was completed by filling all slots on the board (four pegs for level 1 and nine pegs for levels 2 and 3). Error was defined as the sum of broken pegs secondary to excessive grasping pressure, dropped pegs from the grasper during transfer, and number of dropped pegs that could not be retrieved and placed in the allotted slots. The Pattern Cutting drill consists of cutting a piece of simulated gauze in a circle or square pattern based on predrawn boundaries. Excessive tension on the gauze can lead to avulsion from the anchoring hooks. Error was defined as the amount of gauze cut outside of the drawn boundaries. Data on completion time, instrument path length, right and left hand errors, and grasping tension were analyzed.

The scores in the haptic-enhanced simulation environment were compared with the scores in the non-haptic model, for all six drills (Peg Transfer and Pattern Cutting at difficulty levels 1, 2, and 3, respectively). Data analysis was performed using Student's *t*-test.

RESULTS

All 10 medical students successfully completed the study. Baseline FLS scores were similar among all participants.

Individual task analysis did not show any significant difference in performance for the simpler Peg Transfer drill. Task completion time, instrument path length, and error quantification demonstrated similar values in the haptic and non-haptic environments at all 3 levels of difficulty (Fig. 2).

For the more complex Cutting Drill, the time to complete the tasks was significantly shorter when force feedback was introduced, at all levels of difficulty (158 ± 56 *versus* 187 ± 51 s, 176 ± 49 *versus* 222 ± 68 s, and 275 ± 76 *versus* 422 ± 220 s at levels 1, 2, and 3, respectively, $P < 0.05$, Fig. 3). The grasping tension was significantly shorter at level 1 (11.2 ± 3.3 *versus* 7.9 ± 1.8), but no significant difference was achieved at levels 2 and 3 (Fig. 4). Data on instrument path length and errors showed a trend towards improved

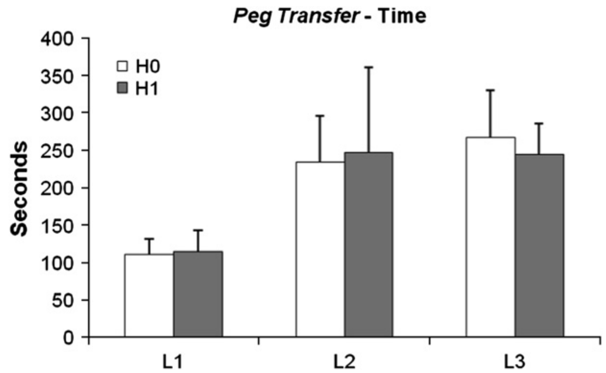

FIG. 2. Time taken to complete the Peg Transfer drill. Data are mean ± standard deviation. L1, difficulty level 1; L2, difficulty level 2; L3, difficulty level 3; H0, no haptics; H1, haptics enhanced.

efficiency from haptics at all difficulty levels, but did not achieve statistical significance (Figs. 5 and 6).

DISCUSSION

Virtual reality simulators are widely recognized as valuable adjuncts for surgical resident training outside the operating room [2, 3]. The American College of Surgeons Residency Review Committee has mandated that all residencies implement skills laboratory curricula by 2008. Basic and Comprehensive Education Institutes, which have been established throughout the country, are required to have box trainers and virtual reality simulators as minimally acceptable equipment [4]. FLS completion is required as of 2010 of U.S. surgical trainees to sit for the American Board of Surgery exams. However, there is still no universally accepted or utilized virtual reality simulation-based training curriculum [5]. This may be due to variations in technical performance, software design, and ability of simulated basic or procedural skills to resemble real-life laparoscopic situations. Furthermore, the expense of these devices represents a limiting factor, with the more

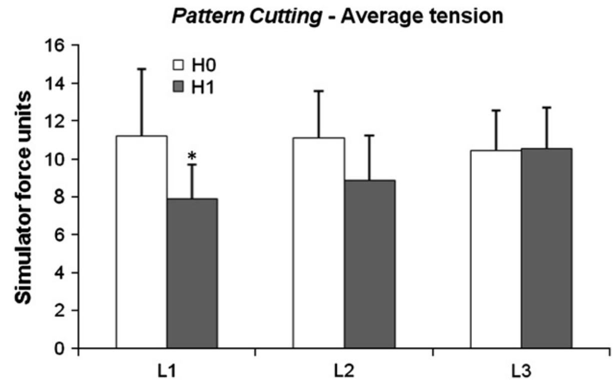

FIG. 4. Average tension applied during performance of the Pattern Cutting drill. Data are mean ± standard deviation. L1, difficulty level 1; L2, difficulty level 2; L3, difficulty level 3; H0, no haptics; H1, haptics enhanced. $^*P < 0.05$.

complex or sophisticated simulators also having the highest prices. The addition of force feedback requires significantly increased resources for the development of software and hardware and, subsequently, is reflected in the cost of acquisition of the simulators. The simulation unit we used in the current study is not distributed without the force feedback option. However, other similar laparoscopic simulators can be purchased with or without the haptic interface. The difference in price is estimated at approximately $20,000. Cost differential on upkeep is difficult to estimate. Based on our own experience with our haptic and non-haptic simulators, we recommend that the service plan also be purchased because of frequent maintenance issues. Based on the cost differential, and the fact that most service plans charge 10% of the cost per year, the yearly increase in maintenance cost would be at least $2000 per machine. Moreover, the value of haptic feedback is not entirely delineated in laparoscopic surgical simulation.

Haptic feedback is defined as the combination of sensory input through the tactile receptors in the skin and the kinesthesic receptors in muscles, tendons, and

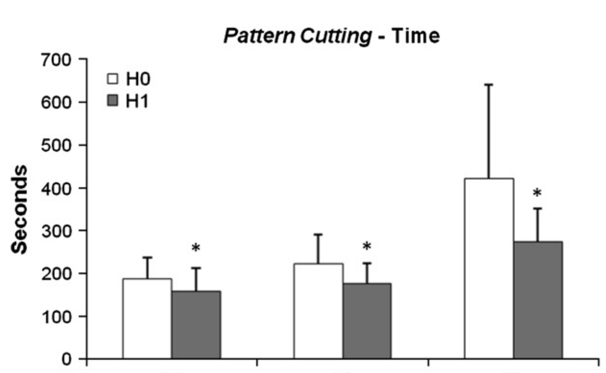

FIG. 3. Time taken to complete the Pattern Cutting drill. Data are mean ± standard deviation. L1, difficulty level 1; L2, difficulty level 2;, L3, difficulty level 3; H0, no haptics; H1, haptics enhanced. $^*P < 0.05$.

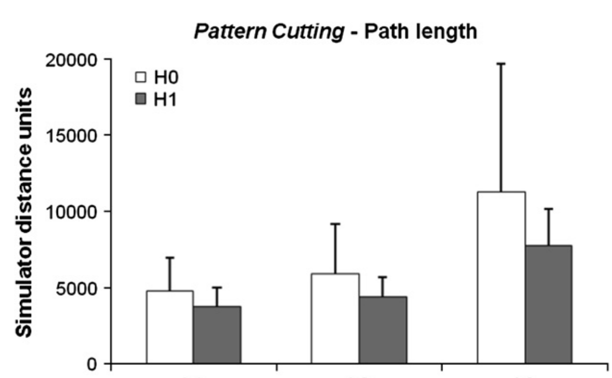

FIG. 5. Path length during performance of the Pattern Cutting drill. Data are mean ± standard deviation. L1- difficulty level 1, L2-difficulty level 2, L3-difficulty level 3, H0-no haptics, H1-haptics enhanced.

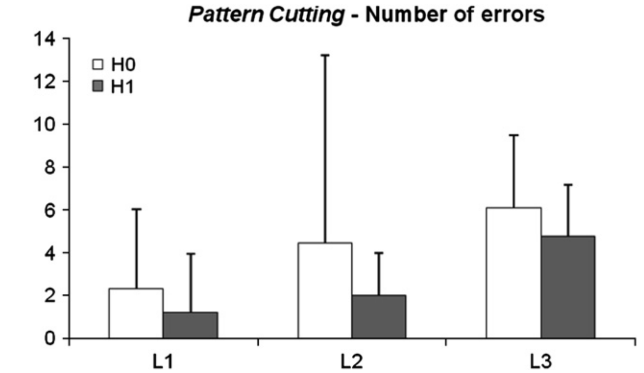

FIG. 6. Number of errors performed during the Pattern Cutting drill. Data are mean ± standard deviation. L1, difficulty level 1; L2, difficulty level 2; L3, difficulty level 3; H0, no haptics; H1, haptics enhanced.

joints [6]. Its value is paramount in open surgery, where "feeling" the tissues is as important as visualizing them. Laparoscopic surgery is characterized by an alteration of this ratio, with brain adaptation for predominant use of visual cues at the expense of tactile cues. Compared with open surgery, in which haptic feedback is a direct measure of the interaction force between the hand or surgical instrument and tissues, in laparoscopy, the tactile sensation perceived by the operator is an unequal combination of multiple forces. These are represented by the interaction of the instrument with the intra-abdominal organs, the friction between the instrument and the port of the trocar, the resistance of the abdominal wall during tilting movements of the instrument, the effects of the operator on the instrument, and the effect of activation of the pincer mechanism of the surgical instrument [7]. Incorporation of realistic haptic feedback into VR surgical simulators seems, therefore, to represent an extremely complex task, with very few simulators having been able to achieve this ideal goal to date.

Moreover, robotic surgery has developed and evolved based solely on visual cues. Although the addition of force feedback seems to be beneficial in performing robotic laparoscopic tasks for both novices and laparoscopic surgeons [8], expert robotic surgeons are able to perform safe operations without this haptic feature.

Several studies have shown benefits from laparoscopic training in the presence of force feedback with hybrid simulators, compared with non-haptic virtual reality simulators [6, 9]. More importantly, other authors have been able to demonstrate that the presence of force feedback in similar training models is beneficial in performance of laparoscopic drills [10, 11].

Therefore, it is not clear yet to what extent the addition of haptic feedback to a laparoscopy simulator is valuable in acquiring surgical skills transferable to the operating room. Our study hypothesis was that performance of laparoscopic drills on the same simulator is enhanced in the presence of force feedback. For this purpose, individual student performance was compared both with and without the haptic feature.

In the more advanced tasks, haptics allows superior precision, resulting in faster completion of tasks and a trend toward fewer technical errors. In the more basic tasks, haptic-enhanced simulation did not demonstrate an appreciable performance improvement among our trainees.

Some limitations of our study are represented by the small number of participants and the limited number of tasks performed. We believe that increasing the number of subjects would result in no significant difference in performance for the simpler task (Peg Transfer), regardless of the sample size. We feel the skills involved in this task are simple enough that adding tactile feedback does not affect the outcome. However, the more complex Pattern Cutting task would likely show more significance in the presence of force feedback, particularly for path length and errors. Based on the conclusions of the current study, potential future venues are represented by assessment of the role of tactile feedback with larger groups for more advanced procedural simulations, such as laparoscopic cholecystectomy, suturing and knot tying, and lysis of adhesions.

When designing the study, we decided to use simulation drills that are similar to the FLS tasks, since successful performance of the five components of the FLS exam was associated with improved resident performance in the operating room. Unfortunately, at the time our study was performed, only two out of the five FLS drills (Peg Transfer and Pattern Cutting) were accurately replicated by the Laparoscopy VR simulator. More drills are currently available, and the manufacturers plan to have all five FLS tasks available in the simulated environment in the future.

These data suggest that the additional expense of currently available haptic-enhanced laparoscopic simulators for surgical residency programs may be justified for advanced skill development in surgical trainees, particularly as technology continues to improve and more advanced procedural simulations become available. Efforts should continue to attempt to achieve and maintain proficiency utilizing these innovative devices as valuable adjuncts to surgical training.

REFERENCES

1. Panait L, Bell RL, Roberts KE, et al. Laparoscopic Operative Skills are Predicted by Virtual Reality Simulator Performance. Paper presented at: Proceedings of the 89th Annual Meeting of the New England Surgical Society, September 2008; Boston, MA.
2. Aggarwal R, Ward J, Balasundaram I, et al. Proving the effectiveness of virtual reality simulation for training in laparoscopic surgery. Ann Surg 2007;246:771.

3. Sturm LP, Windsor JA, Cosman PH, et al. A systematic review of skills transfer after surgical simulation training. Ann Surg 2008; 248:166.
4. American College of Surgeons Program for Accreditation of Education Institutes http://www.facs.org/education/accreditationprogram/index.html Accessed January 3, 2009.
5. Scott DJ, Cendan JC, Pugh CM, et al. The changing face of surgical education: simulation as the new paradigm. J Surg Res 2008;147:189.
6. Botden SM, Torab F, Buzink SN, et al. The importance of haptic feedback in laparoscopic suturing training and the additive value of virtual reality simulation. Surg Endosc 2008;22:1214.
7. Picod G, Jambon AC, Vinatier D, et al. What can the operator actually feel when performing a laparoscopy? Surg Endosc 2005;19:95.
8. Tholey G, Desai JP, Castellanos AE. Force feedback plays a significant role in minimally invasive surgery: Results and analysis. Ann Surg 2005;241:102.
9. Botden SM, Buzink SN, Schijven MP, et al. Augmented *versus* virtual reality laparoscopic simulation: what is the difference? A comparison of the ProMIS augmented reality laparoscopic simulator versus LapSim virtual reality laparoscopic simulator. World J Surg 2007;31:764.
10. Kim HK, Rattner DW, Srinivasan MA. Virtual-reality-based laparoscopic surgical training: The role of simulation fidelity in haptic feedback. Comput Aided Surg 2004;9:227.
11. Strom P, Hedman L, Sarna L, et al. Early exposure to haptic feedback enhances performance in surgical simulator training: A prospective randomized crossover study in surgical residents. Surg Endosc 2006;20:1383.