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and Other Interventional Techniques

Comparison of video trainer and virtual reality training systems on acquisition of laparoscopic skills

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Abstract. Training on a video trainer or computer-based minimally invasive surgery trainer leads to improved benchtop laparoscopic skill. Recently, improved operative performance from practice on a video trainer was reported. The purpose of this study was three fold: (a) to compare psychomotor skill improvement after training on a virtual reality (VR) system with that after training on a video-trainer, (VT) (b) to evaluate whether skills learned on the one training system are transferable to the other, and (c) to evaluate whether VR or VT training improves operative performance. For the study, 50 junior surgery residents completed baseline skill testing on both the VR and VT systems. These subjects then were randomized to either a VR or VT structured training group. After practice, the subjects were tested again on their VR and VT skills. To assess the effect of practice on operative performance, all second-year residents ($n = 19$) were evaluated on their operative performance during a laparoscopic cholecystectomy before and after skill training. Data are expressed as percentage of improvement in mean score/time. Analysis was performed by Student's paired *t*-test. The VR training group showed improvement of 54% on the VR posttest, as compared with 55% improvement by the VT group. The VR training group improved more on the VT posttest tasks (36%) than the VT training group improved on the VR posttest tasks (17%) ($p < 0.05$). Operative performance improved only in the VR training group ($p < 0.05$). Psychomotor skillsimprove after training on both VR and VT, and skills may be transferable. Furthermore, training on a minimally invasive surgery trainer, virtual reality system may improve operative performance during laparoscopic cholecystectomy.

Key words: Surgical education — Laparoscopy — MIST VR — Video trainer — Operative performance — Skills training

The deve lopment of technical skill is fundamental to the process of becoming a surgeon. Traditionally, surgeons have honed their skills in the operating room through hands-on experience with veteran mentors. This manner of teaching effectively trains surgeons in traditional open surgical techniques, but is costly in terms of time, resources, and patient morbidity [2]. Over the past decade, minimally invasive surgery has revolutionized general surgery, posing new obstacles for experienced surgeons attempting to acquire laparoscopic skills [4]. As a result, the development of efficient ways to teach surgeons to perform minimally invasive procedures safely, efficiently, and effectively is a key area of interest in surgical education. Technical skill training outside the operating room may be a cost-effective and less labor intensive adjunct to traditional training in the operating room.

Several training systems exist. Training on cadaver specimens exposes the surgeon to anatomy identical to that found in living counterparts. Tissues found in these specimens, however, can be less pliable and distinctive in appearance. Additionally, cadavers are costly and of limited availability. Mammalian animal models are readily obtainable and less expensive than cadaver models. Their anatomy differs from that of humans, however, and ethical issues exist concerning their use for experimental purposes. Practice of new skills in live models is important before clinical application, but inanimate models such as video trainers and computer

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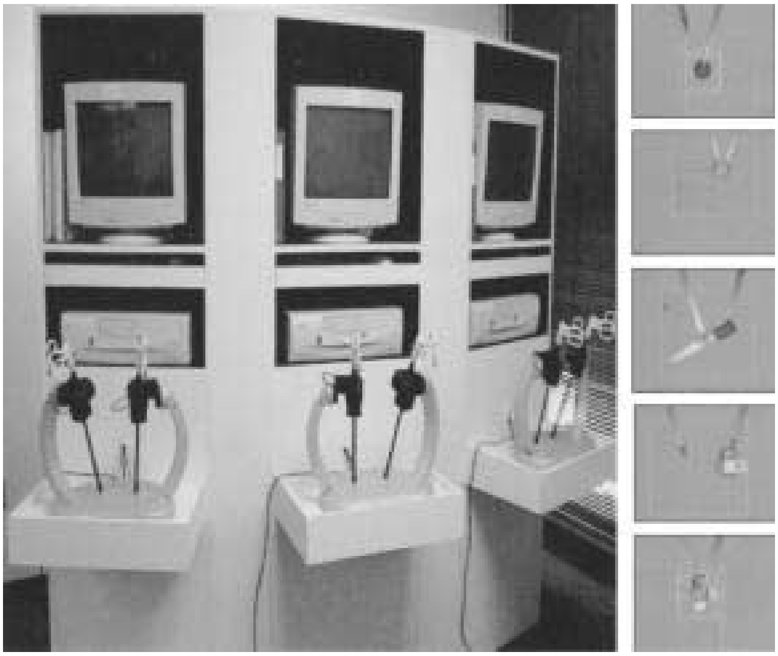

Fig. 1. Southwestern Center for Minimally Invasive Surgery Minimally Invasive Surgery Trainer, Virtual Reality (MIST VR, Virtual Presence, England) module was used for resident training. Five of six tasks from Core Skills One are shown.

simulators represent useful adjuncts. Bench models, although criticized as "unrealistic," are safe, readily available, and inexpensive,requiring little supervision and offering unlimited practice.

Several types of laparoscopic training systems have been developed over the past 5 years including the Minimally Invasive Surgical Trainer, Virtual Reality (MIST VR; Virtual Presence Medical, London, UK), and the video-trainer (VT). The MIST VR (Fig. 1) consists of a structural frame holding two laparoscopic instruments electronically linked to a personal computer. Movement of the surgical instruments, once the task begins, allows for proper angles of approach to the surgical field. Instrument movement is displayed on the computer screen, three-dimensionally, and in real time. Trainees are guided through six exercises of progressive complexity modeled after movements needed to perform a laparoscopic cholecystectomy. Performance is recorded automatically in terms of time (s), errors (pass-pointing, crossing instruments,) economy of motion (actual path relative to computer-determined ideal path), and economy of diathermy. No haptic feedback is available.

Video trainers (Fig. 2), on the other hand, are composed of frames supporting traditional laparoscopic video monitors, light sources, and camera systems. The frame forms a box inside which premanufactured tasks, such as intracorporeal suturing of two pieces of foam, are performed. Speed, measured by the trainee him- or herself, is recorded as the measure of performance. Surgical educators such as Rosser et al. [8], Reznick et al. [1, 5, 6], Taffinder et al. [12], and Derossis et al. [3] have been instrumental in evaluating and validating these models. At the University of Texas Southwestern Medical Center, we have shown that intense training on VTs may improve psychomotor skill and performance in the operating room [10]. However, at this writing, no comparison of the two training systems has been performed.

The purpose of our study was threefold. First, we evaluated whether a virtual reality trainer (MIST VR) helps to develop video–hand–eye dexterity better than an intense laparoscopic VT skills curriculum. Second, we addressed the question whether skills are transferable between laparoscopic training systems. Third, we evaluated whether improvement in psychomotor skills translates into improved operative performance during laparoscopic cholecystectomy. Finally, we gathered subjective data regarding resident preference between the two training systems.

Materials and methods

Between July 1999 and June 2000, 50 first- and second-year surgery residents (R1's and R2's) rotating on general surgery services at Parkland Memorial Hospital were enrolled in the study. All the residents (31 R1's and 19 R2's) gave informed consent under a protocol approved by the University of Texas Southwestern Medical Center Institutional Review Board. For the study, 25 residents were randomized to the VT group, and 25 to the MIST VR group. Of the 50 residents, 49 completed the study. One first-year resident scheduled to be part of the MIST VR training group did not complete all aspects of the study because of scheduling difficulties.

The MIST VR (Fig. 1) was based on a personal computer using Windows NT 4.0 running MIST VR, Version 1.2 and Core Skills One. The personal computer was configured with a Pentium II 450 MHz processor, 64 MB of RAM, and a 17-in. color monitor (Fig. 1). The laparoscopic interface was an Immersion Corporation (San Jose, CA, USA) unit with a foot pedal added for the diathermy tasks. The MIST VR tasks have been described in detail [12], but are reviewed here briefly.

In task 1, grasping tissue is simulated. The user grasps a sphere, transfers it to a three-dimensional (3D) box and releases it. In task 2, the procedure is repeated with the addition of a transfer of the sphere to the other grasper before transfer to the 3D box. Task 3 simulates running the bowel. The trainee traverses a color-coded cylinder in a hand-over-hand fashion. In task 4, replacing a laparoscopic instrument in the peritoneal cavity is simulated. The user grasps the sphere with one hand while the other hand is removed from the field of view before being reinserted. In tasks 5 and 6, diathermy (electrocautery) of a vessel is simulated. In task 5, the user is prompted to cauterize three targets

Fig. 2. Southwestern Center for Minimally Invasive Surgery Guided Endoscopic Module (GEM). This six-station video-trainer (Karl Storz Endoscopy, Culver City, CA, USA) is used for resident training. Sketches of the five laparoscopic tasks are shown [11].

connected to the sphere. This requires coordination of hand movement with use of a foot-pedal. In task 6, the procedure is repeated, but incorporates use of the opposite hand. In all tasks except task 3, the user does two repetitions, starting with each hand before the task is complete.

The SCMIS GEM (Karl Storz Endoscopy, Culver City, CA, USA) (Fig. 2) is composed of a frame housing a Sony HR Trinitron 15-in. color monitor, Karl Storz Xenon 175 light source, and Telecom SL camera box with a 0° 10-mm laparoscope. The modular GEM trainer, as seen in part in multiple other venues, was designed by the principal investigator and manufactured by Storz. Five laparoscopic tasks, which have been described elsewhere [10], were used in the VTs. They were chosen because they were quantifiable and had been used successfully in previous studies at our institution. The five tasks included the suture foam, the bean drop, the triangle transfer, the rope drill, and the checkerboard.

Before beginning the study, the residents were instructed how to perform all the tasks and watched demonstrations of each task being performed. No residents had prior formal training on either the MIST VR or the VT system. No practice was permitted before testing except for the intracorporeal suture drill on the video trainer VT, for which a single practice was allowed to familiarize the resident with the mechanical workings for the Endostitch (USSC, Norwalk, CT, USA) device.

During week 1, all first- and second-year residents performed baseline skills testing on both the MIST VR and the VT. Baseline scores on the video trainer were derived by computing each resident's average score (time elapsed in seconds) during three repetitions of each task. During training sessions, each resident recorded his or her own time in seconds using a stopwatch. The MIST VR training system provided automatic recording of trainee performance in multiple performance parameters including errors, economy of motion with the left and right hands, and economy of diathermy. At the time when this study was conducted, no composite score encompassing all measures of performance was available on the MIST VR system. As a result, in collaboration with the Department of Academic Computing at the University of Texas Southwestern Medical Center, we developed a method for consolidating all the performance data into one composite score to facilitate use of the data in this and other related studies [9].

After baseline testing was completed, all the residents were randomized to practice on either the MIST VR or the VT. Randomization was performed using a random digit assignment method. Practice over the next 2 weeks (weeks 2 and 3) consisted of 10 one-half hour sessions (Monday through Friday) on each trainee's respective training system. During the designated practice times, residents were excused from their clinical responsibilities. Residents chose which task to practice in which order. However, they were encouraged to practice all the tasks during each session. During week 4 when the 2-week session was complete, each resident underwent post training testing on both the MIST VR and the VT to evaluate improvement in skill level on the training system tasks.

To evaluate whether practice on either system correlated with an improvement in operative performance, all second-year residents (n = 19) performed laparoscopic cholecystectomies before and after the training period. All the cholecystectomies were performed for symptomatic cholelithiasis. Attending surgeons of the general surgery service on which the laparoscopic cholecystectomies were completed were asked to serve as first assistant during the operations. Independent faculty surgeons not involved in the case, used a global assessment tool to evaluate the resident's operative performance. Faculty evaluators were blinded to the resident's given training modality.

The residents used a one-handed or two-handed method to perform the laparoscopic cholecystectomy, according to the faculty surgeon's preference. The faculty surgeons were instructed to allow the resident to perform the operation with as much independence as possible, while ensuring patient safety. The residents were prompted to make key decisions regarding the sequence of steps in the operation, and were told to direct the assistant to provide adequate assistance. At the same time, the residents were quizzed on such things as location of key anatomic landmarks and their operative plan. Each performance was rated on a scale of 1 (worst) to 5 (best), with explicit descriptors helping anchor the low, middle, and highest scores on the scale. The composite score then was calculated inthe form of a percentage. The global assessment tool has been validated and described elsewhere in detail by Reznick [7].

Participants also completed a questionnaire at the beginning and end of the study. Surveys assessed baseline and interval laparoscopic operative experience as well as perceived level of competency before and after the study. Residents also were asked whether they found training on the MIST VR or VT to be effective and which system they preferred to use.

Statisticians at the Department of Academic Computing Services, University of Texas Southwestern Medical Center, performed the data analysis. Video trainer and MIST VR scores as well as global assessment scores, before and after training, were compared. Within-group changes were analyzed using paired comparison t-tests. Two sample t-tests were used to compare between-group baseline performance. Intergroup comparisons of improvement were accomplished via analysis of covariance, using the pretraining observation as the covariate. Questionnaire data were compared using chi-square analysis. Differences were considered significant when the p was less than 0.05.

Table 1. Minimally Invasive Surgical Trainer, Virtual Reality (MIST VR) task performance[a]

Group	Pretraining score	Posttraining score	p
VR trained ($n = 24$)	36.0 ± 0.96[b]	55.5 ± 1.2[c]	<0.001
VT trained ($n = 25$)	35.8 ± 0.86	41.8 ± 0.90	<0.001

[a] Scores are unitless and represent a composition of all performance parameters, with higher scores representing superior performance.
[b] p = NS versus VT trained
[c] $p < 0.01$ versus VT trained
VR, virtual reality; VT, video trainer; NS, not significant

Table 2. Video-trainer task performance[a]

Group	Pretraining time (sec)	Posttraining time (sec)	p
VR trained ($n = 24$)	100.8 ± 6.2[b]	64.3 ± 2.9[c]	<0.001
VT trained ($n = 25$)	95.4 ± 6.1	43.4 ± 3.4	<0.001

[a] Lower time represents superior performance.
[b] p = NS versus VT trained
[c] $p < 0.01$ versus VT trained
VR, virtual reality; VT, video-trainer; NS, not significant

After their rotation, residents randomized to train on one of the two training systems were offered the opportunity to train on the other system for their own educational benefit. The data from repeat trainees were not included as part of this study.

Results

Psychomotor skills evaluation

Residents who trained on the MIST VR system practiced each task an average of 37 times (range, 35–38 times). The VT trainers practiced each task an average of 32 times (range, 28–42 times). The number of repetitions performed during the training period for each task varied as a result of resident preference for some tasks over others. Improvement was defined as the difference between baseline and final scores. Baseline psychomotor skill performance on the MIST VR tasks was comparable for both groups ($p = 0.86$). Baseline VT task performance for both groups was comparable as well ($p = 0.56$). The MIST VR task performance improved significantly (higher scores) for residents who trained on both the MIST VR ($p < 0.001$) and the VT systems ($p < 0.01$), as seen in Table 1. Improvement of the MIST VR group exceeded that of the VT group ($p < 0.001$). As seen in Table 2, an improvement in VT task performance (lower scores) was also noted for both the MIST VR ($p < 0.001$) and the VT-trained groups ($p < 0.001$). For these tasks, the VT group improved more than the MIST VR group ($p < 0.001$). We attempted measuring whether skills were transferable between the two systems by evaluating the change in performance on the system on which the resident trained as well as the system on which he or she had minimal experience. Two sample means were analyzed and adjusted for variability. Crossover improvement appeared to be greater for the residents trained on the MIST VR system than for the residents trained on the VT system, although the performance of both groups improved ($p < 0.01$) and such comparison is of questionable further significance.

Minimally Invasive Surgical Trainer, Virtual Reality (MIST VR) task performance Video-trainer task performance

Operative Performance

There was no difference in global assessment composite scores between the MIST VR and VT training groups at baseline ($p = 0.55$). Improvement in global assessment composite scores (operative performance) was identified for the MIST VR training group when analysis was performed on scores given by matched observers ($p = 0.05$), matched observers plus assistants ($p < 0.01$), and all observers combined ($p < 0.01$). No statistically significant improvement in operative performance was identified in the VT training group, who in this study served as controls subjects. Table 3 contrasts the results for the all-observer assessments. No difference was identified between the posttraining MIST VR and VT scores on the global assessment ($p = 0.40$). Global assessment of operative performance

Questionnaire Data

According to the questionnaire data, baseline and ending laparoscopic operative experience for both training groups was comparable. The baseline number of cases per resident acting as either the surgeon or first assistant was 5.32 ± 1.78 for the MIST VR group and 4.56 ± 1.21 for the VT group ($p = 0.76$). At the beginning of the study, 6% of the residents reported feeling comfortable with their current laparoscopic technical skills. When the study was completed, that number had increased to 43% ($p < 0.05$). When asked if they felt more comfortable with their laparoscopic technical skills after the 2-week period of training, 94% of the residents responded affirmatively. Similarly, 84% of the subjects thought training outside the operating room on either the MIST VR or VT system had improved their ability

Table 3. Global assessment of operative performance

Group	Pretraining score (%)	Posttraining score (%)	p
VR trained (n = 10)	40.9 ± 5.2^{a}	48.3 ± 4.4^{a}	< 0.01
VT trained (n = 9)	36.3 ± 5.4	40.6 ± 5.7	NS

[a] p = NS versus VT trained
VR, virtual reality; VT, video-trainer; NS, not significant

to perform laparoscopic procedures in the operating room. When asked whether they thought MIST VR and VT systems were effective teaching tools in general, and if given a choice, which system they would choose, residents gave the following answers. Whereas 93% thought VT was effective, 79% thought MIST VR was an overall effective method for enhancing laparoscopic skill. Of the residents, 77% preferred VT training over VR training overall, and 83% thought VT was a more effective training tool. Reasons for preferring VT were reflected in statements that VT is ''more realistic,'' providing tactile feedback and better depth perception. No significant difference was noted between those who trained on the MIST VR and those who trained on the VT for any of the above responses.

Discussion

Mastery of technical skill is crucial to surgical training. With the growing complexity encountered in performing minimally invasive surgery, training in the operating room alone may be inefficient and impractical. Practice using inanimate models increases psychomotor skills and translates into improved performance in the operating room [9]. The aim of the current study was to determine whether a virtual reality–based training system, MIST VR, was as effective as training on more common VT systems. Several noteworthy findings deserve discussion. Training of residents on both VR and VT systems effectively improves psychomotor skills. Skill developed on one system appears to be transferable to the other modality. These findings suggest that at least some of the learning that occurs with these inanimate trainers is transferable to other laparoscopic tasks. Interestingly, when crossover data were compared, a trend toward greater improvement was found with the MIST VR system.

The most important question, however, is whether training on inanimate systems is transferable to the operating room. In this study cohort, MIST VR, but not VT, training significantly improved performance of a laparoscopic cholecystectomy in the operating room. These findings indicate that development of laparoscopic skills outside the operating room may be transferable to actual performance of laparoscopic surgery, and that specifically, training using the virtual reality system is effective in this regard. The lack of improvement with VT trainers is, however, perplexing considering our previous findings [9]. There are several possible reasons for the discrepancy. First, the power of the study to detect an improvement in operative performance in the VT-trained group may have been too low. Also, because practice sessions in both studies were self-directed, the quality of training may have varied between studies. During the initial study, emphasis on performance of laparoscopic surgery by residents was growing in our program, and the concept of laparoscopic training outside the operating room was novel. Over time, residents may have sacrificed accuracy for speed, and practice may not have been as effective. This problem would not have been identified by our data because speed was the only endpoint measured in the VT group. Because the MIST VR system reports error with each task performance, residents may have striven to minimize error, and learning may have been enhanced. In future studies using the VT, an additional measure of performance (errors) as well as supervision and feedback during practice sessions may optimize performance.

On the other hand, the discrepancy may be attributable to less stringent operative assessments. In the previous study, extraordinary efforts were made to ensure that scores were assigned by a limited number of evaluators, that more than one evaluator was present at each operation, and that there was overlap of evaluators between the pre- and posttraining cholecystectomies. However, because of limitations on faculty availability, the number of evaluators was expanded for this study, and there was greater variability in number and matching of evaluators for the operation, thereby introducing a greater chance for rater bias. In addition, matched, nontrained controls were not used since, because on the basis of previous data, we believed that all residents should undergo skills training early during their second year or sooner.

In addition to study design, other recognized shortcomings of the training systems or the study itself included the fixed operating height of both training systems and the use of tasks without proven close association with actual surgical tasks. Although the discrepancy in results between this and our previous study raises concern about the overall effectiveness of VT training, we believe that the difference is attributable more to the sensitivity of the evaluation process than to the training process.

Residents preferred VT training, but performed better on the MIST VR, suggesting that it was more useful as a training system. Greater effectiveness of the MIST VR was suggested not only by the improved performance in the operating room, but by crossover skills demonstrated during posttraining testing. The reasons for this difference are not clear from the data, but we speculate that differences in the training system may be responsible for the variance. Because performance during VT training is measured only by time to complete the task, MIST VR automatically records data as the task is completed on the time to complete the task, the errors, the economy of motion with both right and left hands, and the economy of diathermy. Thus, the composite score used to evaluate effectiveness of the training was based on many aspects of performance. Moreover, the device will not allow a task to be completed until it is performed accurately, according to the rules of the task. The operator, forced to be accurate, cannot easily sacrifice speed for accuracy. This may ensure effective training. Because of this problem, Rosser et al. [8] are developing a method to measure the number of errors incurred on the VT-performed tasks. Such a system was not used for VT training in the current study. The MIST VR, by design, has this feature built into its training protocol.

In summary, residents feel more comfortable after skills training outside the operating room and are more confident in performing laparoscopic procedures after training. They clearly improve their skill level on either VR or VT training systems, and it appears that skills are transferable to the operating room. Use of these laparoscopic training systems may be useful before the resident moves on to preceptor-based training in the operating room. At this time, the VR system, although not as realistic, may be more effective in training residents because it ensures accurate accomplishment of tasks and evaluates trainees using several parameters in addition to speed.

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