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and Other Interventional Techniques

Comparison of the sensitivity of physical and virtual laparoscopic surgical training simulators to the user's level of experience

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Abstract
Background: The recent focus on quality of care and patient safety has been accompanied by increased interest in standardizing the training for laparoscopic surgeons. Studies have shown that laparoscopic simulators can be used to train surgical skills. Therefore, we designed an experiment to compare the effectiveness of two popular training systems. One system was based on a physical model, whereas the other used a virtual reality model.
Methods: A total of 32 medical students and residents were tested on both simulators. Time required for task completion and number of errors committed were recorded and compared.
Results: The physical training system differentiated among experience levels on three of the five tasks when time was used as a measure and four of five tasks when score was used, whereas the virtual reality system yielded statistically significant results in eight of 13 tasks for time and in five of 13 tasks for score.
Conclusion: The physical model is more sensitive than the virtual reality one in detecting differences in levels of laparoscopic surgical experience.

Key words: Simulation — Laparoscopic skills — Surgical training — Virtual reality — Laparoscopic surgery — Fundamentals of Laparoscopic Surgery (FLS) surgical simulator — Minimally Invasive Surgical Trainer–Virtual Reality (MIST-VR) surgical simulator

The introduction of minimally invasive surgery has sparked a new interest in the effect exerted by human factors within the complex sociotechnical environment of the operating room, particularly in the areas of ergonomics and the surgeon's posture at the operating table. At the same time, more attention is being paid to the surgeon's cognitive, psychomotor, and perceptual capabilities [3]. Competent performance of laparoscopic surgery requires special psychomotor skills that are different from the ones needed for open surgery [14]. Patient safety and financial issues have created a need to find a new way for trainees to develop laparoscopic skills outside the operating room [5, 16]. This new environment has led to the development of surgical simulators that give residents the opportunity to practice the various laparoscopic techniques before being asked to perform real-time procedures on patients in the clinical setting [14].

Research has demonstrated that training with surgical simulators can improve cognitive and visuomotor skills that may be transferable to the operating room [17]. Currently, two popular training simulators are being used to investigate the effectiveness and validity of this training approach—the Minimally Invasive Surgical Trainer–Virtual Reality (MIST-VR) (Immersion Corporation, 801 Fox Lane, San Jose, CA, USA), and the Fundamentals of Laparoscopic Surgery (FLS). The virtual reality simulator has been shown to be an effective training tool in that it can distinguish among novice, junior, and experienced surgeons in several basic surgical skills [2, 9, 11]. Similarly, the real physical simulator has also been proven to discriminate between experience levels [7]. In addfition, training on the FLS can be correlated to improvements on laparoscopic pig procedures *in vivo* [8]. The FLS has been selected by the Society of American Gastrointestinal Endoscopic Surgeons (SAGES) as to its official trainer. These two types of systems require the users to perform different types of tasks. They have been evaluated individually, but heretofore the virtual reality simulators have not been compared to the real/physical box trainers.

This study was designed to compare the relative effectiveness of the two simulators. The first step toward assessing the usefulness of a trainer is to determine its

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Table 1. Description of the 13 MIST-VR tasks used in the study

No. Name	Description
1. Acquire Place	A sphere is grasped with one tool and placed in a box.
2. Transfer Place	A sphere is grasped, transferred to another tool, and placed in a box.
3. Transversal	A cylinder is grasped in a specified section and moved down while alternating tools.
4. Withdraw Insert	A sphere is grasped with one tool and touched with a second tool; the second tool is removed from the screen and then reinserted; the sphere is then touched again while inside a box.
5. Diathermy	A box fixed to a sphere is cauterized with the diathermy tool.
6. Manipulation Diathermy	Combined tasks 4 and 5.
7. SD Stretch	The highlighted end of a barbell is grasped and stretched until there is a change in color, indicating the correct length; then
8. SC Clip	The highlighted section of a barbell is clipped.
9. SC Stretch Clip	Combined tasks 7 and 8.
10. SD Diathermy	The shaft of a barbell is cauterized moving from the fixed to highlighted end.
11. SD Stretch Diathermy	Combined tasks 5 and 7.
12. Start Stitch	A needle is grabbed and pushed through tissue at a specified location.
13. Half Square Knot	A needle is grasped with the right tool, a thread is wound around the left tool shaft, and then the ends are tightened to create a knot.

MIST-VR, Minimally Invasive Surgical Trainer – Virtual Reality

Table 2. Description of the five FLS tasks used in the study

No. Name	Description
1. Peg Transfer	Pegs are acquired from one pegboard using one tool, transferred to the other tool, and placed on a new pegboard. The task is then repeated in reverse.
2. Cutting Pattern	Endoscopic scissors are used to cut out a prescribed circle from a piece of gauze.
3. Endoloop	A ligating loop is tightened around a specified section of a sponge appendage.
4. Intracorporeal Knot	A stitch is made through marked spots on a Penrose drain; three double-throw knots are then tied and secured.
5. Extracorporeal Knot	After the stitch is made, three knots are tied outside of the simulator box, and a knot pusher is used to slide and tie the knot at the suture site

FLS, Fundamentals of Laparoscopic Surgery

ability to differentiate among experience levels consistently and reliably. Therefore, we evaluated and compared the ability of each simulator to predict the user's surgical performance as a function of his or her year in the residency program. As far as we know, this is the first study that has compared the FLS and the MIST-VR [15].

Materials and methods

The study was conducted as a randomized control trial and was carried out at the Center of Minimally Invasive Surgery of Tufts–New England Medical Center (Boston, MA, USA) and in the Stamford Hospital (Stamford, CT, USA) between July 2003 and April 2004. A total of 32 subjects (five medical students, seven interns, five 2nd-year residents (PGY-2),6 3rd-year residents (PGY-3), seven 4th-year residents (PGY-4), and two fellows) from Tufts–New England Medical Center, Stamford Hospital, and Tufts Medical School participated in the study. All interns, residents, and fellows belonged to the departments of general surgery and obstetrics and gynecology of the two hospitals. All subjects volunteered and were highly motivated. The study protocol was approved by the local ethics committee, and participants gave their informed consent. Tufts–New England Medical Center is one of the six centers across the United States and Canada that have been selected by SAGES to offer certification testing of laparoscopic skills using the FLS.

The MIST-VR system is comprised of a 2.8-GHz Pentium 4 PC, with 256 MB RAM and a 13-in computer monitor, connected to a laparoscopic tool base with two tools each having 5 degrees of freedom. The monitor was placed at eye level, and the tool base was positioned at waist level directly in front of the subject. The MIST-VR creates a virtual environment on the monitor display that shows the position and the movements of the tips of the two tools in real time. The user can manipulate the two instruments and grasp various objects, such as spheres, tubes, needles, etc. The tasks can have various degrees of difficulty. The FLS system consists of a box frame, laparoscopic tools, two trocars, an opaque plastic cover, an endoscopic camera with a light source, and a 13-in TV monitor. The monitor was placed at eye level to the right of the subject, with the laparoscopic tools and camera inserted into the box to simulate laparoscopic surgery.

The subjects began each session by filling out a short questionnaire with biographical and surgical training information.

Virtual simulator tasks were performed on the MIST-VR. Each session was made up of 13 tasks (Table 1). Before each task, a demonstration of that task was shown, accompanied by a verbal explanation by the researcher.

Real model tasks were performed on the FLS. Each session was made up of five tasks (Table 2). Subjects were first shown a video introduction that summarized the basics of laparoscopic surgery and gave an overview of all tasks, as well as in-depth description of the task objectives.

Each participant performed three trials of the 13 tasks on the MIST-VR and one trial of the five tasks on the FLS. All participants were tested on both trainers. The order of trainers was counterbalanced. The order of the tasks within each trainer performance is listed in Tables 1 and 2.

Overall score on the MIST-VR system is based on the following five parameters: the sum of time to task completion, number of errors, economy of movement of the right tool, economy of movement of the left tool, and economy of diathermy use during the tasks 5, 6, 10, and 11. Economy of movement of the instruments was assessed as the proportion of the distance traveled by the tip of the instrument when it exceeded the optimal distance. Economy of diathermy was assessed as the total burn time. The scores from the MIST-VR were calculated as the sum of the time to completion, number of errors, and efficiency of

Table 3. Average completion times (in seconds) for each task on the MIST-VR

Task	Juniors (n = 12)	Mid-levels (n = 11)	Seniors (n = 9)	P value
1. Acquire Place	31.50278	20.32	21.7	0.042
2. Transfer Place	37.62222	19.20667	32.38667	0.076
3. Transversal	57.91111	31.08667	32.55333	0.027
4. Withdraw Insert	30.56111	26.84667	19.26	0.014
5. Diathermy	28.93889	23.80667	24.12	0.032
6. Manipulation Diathermy	58.47778	42.48	46.28	0.013
7. SD Stretch	17.94167	19.67333	18.93333	0.849
8. SC Clip	17.68333	7.606667	12.43333	0.022
9. SC Stretch Clip	27.45278	19.40667	26.96667	0.222
10. SD Diathermy	47.73333	36.94	36.64667	0.007
11. SD Stretch Diathermy	69.65556	58.36	65.5	0.342
12. Start Stitch	42.72813	26.44667	27.86	0.013
13. Half Square Knot	75.9625	56.84	47.94667	0.071

MIST-VR, Minimally Invasive Surgical Trainer–Virtual Reality

Table 4. Score for each task on the MIST-VR

Task	Juniors (n = 12)	Mid-levels (n = 11)	Seniors (n = 9)	P value
1. Acquire Place	52.57222	32.4	36.68667	0.019
2. Transfer Place	53.33611	32.93889	53.34667	0.093
3. Transversal	91.02778	56.56111	55.83333	0.03
4. Withdraw Insert	38.825	43.05	26.74	0.025
5. Diathermy	44.66944	46.26111	47.15333	0.85
6. Manipulation Diathermy	90.98611	98.00556	77.3	0.4
7. SD Stretch	31.51111	36.88889	29.95333	0.647
8. SC Clip	31.91389	31.91389	25.60667	0.08
9. SC Stretch Clip	38.41667	27.61667	38.72667	0.147
10. SD Diathermy	55.31111	43.21667	42.34667	0.007
11. SD Stretch Diathermy	87.6037	73.48333	82.36	0.372
12. Start Stitch	61.78125	43.33333	33.62	0.001
13. Half Square Knot	79.7	65.13889	50.79333	0.09

MIST-VR, Minimally Invasive Surgical Trainer–Virtual Reality

motion. The lower the score, the better the performance. The FLS score follows a normalized standard that has been described in detail elsewhere [8]. This score is also based on time to task completion and number of errors committed, but it does not include economy of motion. An overall score with weighted averages for all five tasks was also calculated for each subject. The higher the score, the higher the performance. This study specifically compared time and scores.

For analysis, participants were divided by level of surgical training into three groups: medical students and interns (juniors), PGY-2 and PGY-3 (mid-levels), and PGY-4, and fellows (seniors). An analysis of variance (ANOVA) was done with an α value of 0.05 to evaluate the times and scores on both simulators. The same person (D.V.A.) evaluated the results for both simulators.

Results

For analysis purposes, the participants' results were reported independently for time to task completion and score. Not all tasks on the MIST-VR were able to distinguish among experience levels in terms of time and score. There was a significant difference in time to task completion between subjects of different experience levels for eight of the 13 tasks (Table 3). However, there was a statistically significant difference in score among experience levels for only five of the tasks (Table 4).

The FLS system was able to differentiate among experience levels on three of the five tasks when time was used as a measure (Table 5) and four of the five tasks when score was used (Table 6). In this case, the higher the score, the better the performance. In general, the more experienced the surgeon, the better the time and score for the task. The senior surgeons performed better than the mid-levels and the mid-levels did better than the juniors on all significant tasks in both time and scores.

Discussion

For many common operations, such as cholecystectomy, antireflux surgery, and bariatric procedures, laparoscopic methods represent the gold standard, and the minimally invasive approach has proven to be superior to open surgery. Benefits include a shorter recovery time, less scarring, and a lower rate of postoperative infection [10]. Increased demand for laparoscopic procedures has created an urgent need for surgeons who are skilled and well trained in these techniques. However, recent opposition to the use of animal models and human cadavers [13] for the training of future surgeons has necessitated greater use of technology in the form of inanimate training models such as virtual reality systems [2].

Computer-assisted simulators have been widely used for many years in the training of pilots and astronauts.

Table 5. Average completion times (in seconds) for each task on the FLS

Task	Juniors ($n = 12$)	Mid-levels ($n = 11$)	Seniors ($n = 9$)	*P* value
1. Peg Transfer	225.49	142.7778	112.575	0.018
2. Cutting Pattern	292.33	196.0111	120.675	0.035
3. Endoloop	190.54	135.4889	98.2	0.059
4. Intracorporeal Knot	902.4778	559.8444	594.55	0.075
5. Extracorporeal Knot	427.36	311.5	274.9	0.010

FLS, Fundamentals of Laparoscopic Surgery

Table 6. Score for each task on the FLS

Task	Juniors ($n = 12$)	Mid-levels ($n = 11$)	Seniors ($n = 9$)	*P* value
1. Peg Transfer	39.35	62.32727	79.075	0.003
2. Cutting Pattern	16.31	27.00909	56.325	0.001
3. Endoloop	15.84	29.40909	57.6	0.020
4. Intracorporeal Knot	4.11	15.81818	29.425	0.072
5. Extracorporeal Knot	11.26	36.19091	48	0.007

FLS, Fundamentals of Laparoscopic Surgery

The application of virtual reality simulators for training in medicine was introduced only in the last decade. The term ‘‘virtual reality’’ refers to ‘‘a computer-generated representation of an environment that allows sensory interaction, thus giving the impression of actually being there’’ [6]. Many of the prototype and first-generation applications of virtual reality are directed at educating medical students and residents [13]. Most of these first applications were based on the Visible Human Project [1] of the National Library of Medicine, which provides a complete database of three-dimensional representations of the human anatomy. However, heretofore, it was not clear how the virtual reality laparoscopic simulators compared to the real/physical box trainers.

Our results show that the physical system (FLS) was better at distinguishing between experience levels than the virtual system. The physical trainer discriminated among all three skill levels within the significant tasks. The FLS also showed that the more experience the participants had, the better and faster they performed. The intracorporeal knot-tying task was the only one that was not statistically significant in the score measure. This can be attributed to the fact that knot-tying is fairly difficult and is not usually taught until later in residency.

The virtual system (MIST-VR) differentiated among the three levels of experience levels only on certain tasks (eight on the time measure and five on score). These results may reflect the nature of the specific tasks that were tested by the MIST-VR. Tasks 1–13 measure different laparoscopic surgical skills, and their level of complexity does not necessarily increase from one task to the next. Table 7 shows a subdivision of the 13 tasks into subgroups based on the similarity of their complexity and the laparoscopic surgical skills that they measure. In each subdivision, the second task is always more complex and demanding than the first (e.g., the Transfer Place is more complex than the Acquire Place). In most cases, the less complex tasks yielded significant results, and the more complex ones yielded nonsignificant results. There are cases where all tasks of a subgroup yielded significant or nonsignificant results. It is also possible that the metrics for measuring performance on fee virtual system are not sensitive enough, or that, due to its novelty, the virtual environment requires more practice for familiarization.

Table 7. p values for time and score on the MIST-VR

Task	Time	Score
1. Acquire Place	0.042	0.019
2. Transfer Place	0.076	0.093
3. Transversal	0.027	0.03
4. Withdraw Insert	0.014	0.025
5. Diathermy	0.032	0.85
6. Manipulation Diathermy	0.013	0.4
7. SD Stretch	0.849	0.647
8. SC Clip	0.022	0.08
9. SC Stretch Clip	0.222	0.147
10. SD Diathermy	0.007	0.007
11. SD Stretch Diathermy	0.342	0.372
12. Start Stitch	0.013	0.001
13. Half Square Knot	0.071	0.09

MIST-VR, Minimally Invasive Surgical Trainer–Virtual Reality
The horizontal lines subdivide the 13 tasks into subgroups, based on the similarity of surgical skills and level of complexity

Although the design of fee tasks offered by the two systems, is not identicall, it appears that the performance metrics are a key factor in determining their usefulness. The MIST-VR scores were calculated by summing of time to completion, number of errors committed, and economy of motion. The FLS scores are weighted by importance of the task and expected practical detriment of fee errors. These metrics should be validated to enable further evaluation of the trainers.

Because virtual reality systems are a new development, it is possible that the participants were less comfortable with this technology than with the physical model. Virtual reality simulators require a mental transformation to progress from viewing the virtual image to completing the fine motor interactions with a real object (the tool handles). The virtual reality trainer also lacks haptic feedback, which is critical for good performance in teleoperation tasks [4, 12]. Therefore, the differences in performance as a function of experience may not be measurable until the residents have become familiar with the new technology. Our research suggests that real simulators may presently be more sensitive than the virtual reality models in detecting differences in levels of laparoscopic surgical experience. However, as virtual reality technology becomes more popular and better developed, we may see a change in its value. Further studies are needed to establish which of the two models is more effective for standardized training of residents and surgeons.

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