Surg Endosc (1999) 13: 1077–1081

Surgical Endoscopy
Ultrasound and
Interventional Techniques

Comparison of laparoscopic performance in vivo with performance measured in a laparoscopic simulator

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Received: 26 March 1998/Accepted: 1 July 1999

Abstract
Background: Laparoscopic skill was measured objectively through a series of seven tasks in an inanimate laparoscopic simulator. Seven analogous skills were tested in an in vivo porcine model. These skills included transferring, cutting, clipping, placement of a ligating loop, mesh placement, and suturing with an intracorporeal and extracorporeal knot. Scoring of each task rewarded precision and speed.
Methods: Twelve PGY3 residents were given a baseline evaluation in the simulator and in the animal model. They were then randomized to either five practice sessions in the simulator (group A) or no practice (group B). Each group was retested in the simulator and in the animal (final test). Scores in vivo were compared by *t*-test for baseline versus final evaluation for each group. Linear regression analysis was used to correlate in vivo and in vitro scores for each task and for the total score (sum of all scores).
Results: Group A showed significant improvement in performance in vivo for cutting, clipping, mesh placement, and suturing with an intracorporeal and extracorporeal knot, as well as in the total score ($p < 0.05$). Group B showed significant improvement in suturing with an intracorporeal and extracorporeal knot, and in the total score. The magnitude of improvement from baseline to final evaluation was significantly greater for group A ($p < 0.05$). There was significant correlation between in vitro and in vivo total scores and the score for each task ($p < 0.05$) except for placement of the ligating loop and mesh.
Conclusions: Performance in an in vitro laparoscopic simulator correlated significantly with performance in an in vivo animal model. Practice in the simulator resulted in improved performance in vivo.

Key words: Laparoscopic training — Laparoscopy — Simulation — Surgical education

Commentary to this article appears on page 1082
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The training and credentialing for laparoscopic surgery in most residency programs is extending beyond the realm of the operating room. Didactic sessions, simulator practice, and animal laboratory training can be organized into comprehensive curricula. Most trainees regard all of these as essential to their training, particularly when learning a new technical skill [8]. Instructors provide a forum that is conducive to learning, reduces stress, and provides opportunity for feedback and remediation.

The purpose of this study was to evaluate and correlate two fundamental teaching tools in laparoscopy: the laparoscopic inanimate simulator and the live animal laboratory. Objective measurements of performance in the animal laboratory were correlated with performance in a laparoscopic simulator. Also, the value of structured practice in an inanimate model on the performance of laparoscopic skills in live animals was assessed.

Materials and methods

Laparoscopic skills were evaluated in an in vivo porcine model and in an inanimate laparoscopic simulator in 12 general surgery residents at the PGY3 level. Laparoscopic skill was objectively measured in vitro through a series of seven tasks using the MISTELS program (McGill Inanimate System for Training and Evaluation of Laparoscopic Skills) [3]. Seven analogous skills were evaluated in the porcine model. After a baseline evaluation in both the simulator and the animal, the 12 residents were randomized to either five weekly practice sessions in the simulator (group A) or no sessions (group B). Each resident was then retested in both the simulator and the porcine model.

The seven tasks performed in the simulator were evaluated for both precision and speed. These tasks ranged from basic to more advanced skills. The MISTELS program has been described in detail previously [3]. The simulator consists of a laparoscopic trainer box measuring 40 × 30 × 19.5 cm (USSC Laptrainer, United States Surgical Corporation, Norwalk, CT, USA) covered by an opaque membrane. Two 12-mm trocars (USSC Surgiport, United States Surgical Corporation, Norwalk, CT) were placed through the membrane at convenient working angles on either side of the 10-mm, 0° laparoscope (USSC Surgiview, United States Surgical Corporation, Norwalk, CT). Four alligator clips within the simulator were used to suspend materials for the various exercises.

The laparoscope and camera (Storz endoskope; telecam, Karl Storz Endoscopy Canada, Toronto, Ontario, Canada) were mounted on a stand at a fixed focal length. This enabled the examinee to work without assistance. The optical system included the laparoscope, camera, light source, and video monitor (Sony Trinitron, 19 inch, Karl Storz Endoscopy Canada, Toronto, Ontario, Canada). Anesthetized female pigs weighing approximately 20 kg were used as the animal model. Animal use conformed to the regulations of the animal care committee.

Performance of the tasks both in the simulator and the animal model were scored for both precision of performance and speed. For each task, in both the simulator and porcine models, a timing score was calculated by subtracting the time to complete the exercise from a preset cutoff time (timing score = cutoff time [seconds] − time to complete the exercise [seconds]). This system rewarded faster performance with higher scores. If the time to complete the exercise exceeded the previously established cutoff time, a timing score of 0 was given. Thus, no negative values were assigned. Precision of performance also was scored objectively by calculating a penalty score for each exercise (see description of exercises). Finally a score was calculated for each exercise by deducting the penalty from the timing score (score = timing score − penalty score). Therefore, the more accurately and quickly a task was completed, the higher the score.

An introductory video demonstrating proper performance of the simulator tasks was shown to each candidate before testing. The tasks were as follows.

Task 1: transferring

Simulator. This task involved lifting each of six pegs from a pegboard with the left hand, transferring it to the right hand, and then placing it on another pegboard. This procedure was then reversed. The cutoff time was 300 s, and a penalty was calculated for pegs dropped outside the field of view.

Animal. This task was performed using a ski needle (USSC 3-0 Polysorb, United States Surgical Corporation). The ski needle was lifted from the right lobe of the liver with the left hand, transferred to the right hand, and placed down on the left lobe. This procedure was then reversed. This task was repeated 3 times. The cutoff time was 240 s, and a penalty was calculated if the needle was dropped out of view (Fig. 1).

Task 2: cutting

Simulator. A circle 4-cm in diameter was marked on a 10 × 10-cm piece of gauze suspended between alligator clips. The candidate was required to use endoscopic scissors to cut out the circle precisely on the mark. The cutoff time was 300 s, and a penalty was calculated as the percentage area of deviation from the area of the perfect circle.

Animal. This task was performed by cutting out a circle 4.5-cm in diameter drawn on a piece of 10 × 10 cm mesh fixed on the diaphragm. The cutoff time was 360 s, and the penalty again was calculated by the percentage area of deviation from a perfect circle (Fig. 2).

Task 3: clipping

Simulator. Hemostatic clips were placed on a tubular foam structure at premarked positions. The candidate was then required to divide the foam precisely on a mark midway between the clips. The cutoff time was 120 s, and a penalty was assessed by measuring the sum in millimeters that the clips or cut deviated from the predrawn lines.

Animal. A segment of small bowel was held up by two assistants. This task required a mesenteric vessel to be dissected, double clipped, and divided between the clips. The cutoff time was 240 s, and a penalty was assessed for insecure hemostasis (Fig. 3).

Task 4: ligating loop

Simulator. This task involved the accurate placement and tightening of a commercially available pretied slip knot (USSC Surgitie, United States Surgical Corporation) on a foam tubular appendage. The cutoff time was 180 s, and the penalty score was calculated by measuring the distance in millimeters of the loop away from the premarked position. A penalty was given if the knot was insecure.

Animal. A segment of small bowel was held up by two assistants. A ligating loop was secured over an area of small bowel mesentery, and the mesentery and tie were cut. The cutoff time was 300 s, and a penalty was given for any bleeding caused by an insecurely placed ligating loop (Fig. 4).

Task 5: mesh placement

Simulator. This task required a mesh 5 cm in diameter to be placed over a previously created 4-cm circular defect in a foam model, then secured with staples using a hernia stapler (USSC Multifire Endohernia 0° 12 mm, United States Surgical Corporation). The cutoff time was 420 s, and a penalty score was given for any insecure staples, for extra staples used to secure placement, and for any uncovered area, and the defect calculated as a percentage.

Animal. An L-shaped area measuring 8 × 8 cm was outlined on the diaphragm. The task required this area to be covered with a mesh measuring 10 × 10 cm, and the mesh to be stapled in position using a nonarticulating hernia stapler. The cutoff time was 420 s, and a penalty was given for any area not covered, any buckled mesh, and any extra staples used to secure placement (Fig. 5).

Task 6: intracorporeal knot

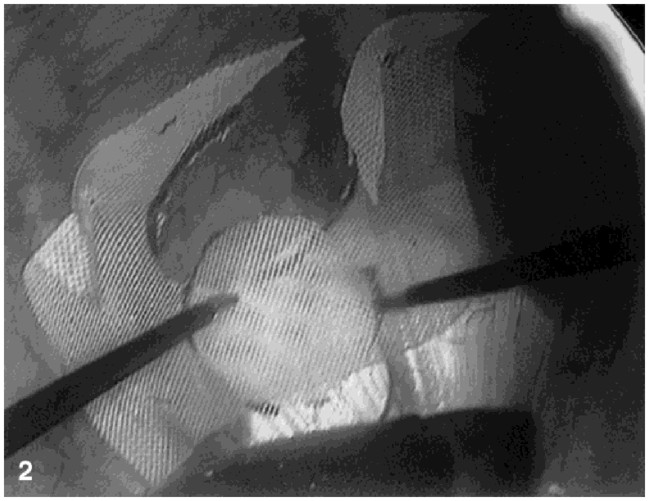
Task 7: extracorporeal knot

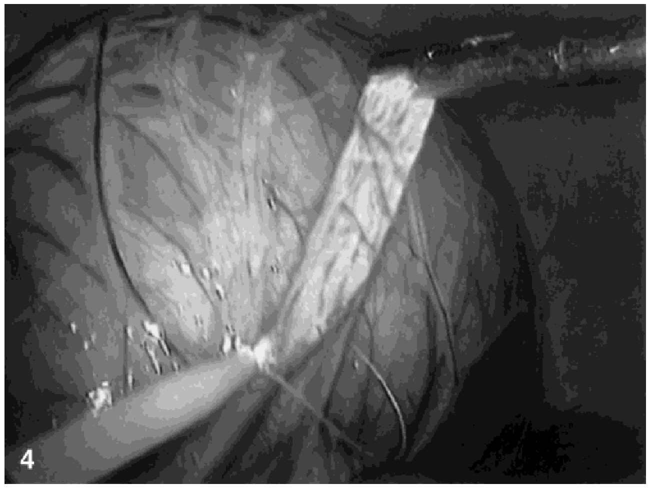
Simulator. This task required placement of a simple suture through premarked points in a longitudinally slit penrose drain. The suture was then tied using either an intracorporeal knot (IC) (task 6) or an extracorporeal knot (EC) (task 7) with the aid of a knot pusher. The cutoff time was 600 s for the intracorporeal knot and 420 s for the extracorporeal knot. A penalty score was calculated to reflect the accuracy and security of the suture. The penalty score was the total of the distance in millimeters from the premarked points at which the suture was placed plus the gap in millimeters if the suture failed to approximate the slit. Additional penalty points were given for the insecurity of the knot (0 points for a secure knot, 10 points for a slipping knot, and 20 points for a knot that came apart).

Animal. Two pieces of small bowel in proximity were approximated using an intracorporeal and subsequently extracorporeal knot. The cutoff time was 600 s for the IC knot and 480 s for the EC knot. A penalty score was given if the knot was insecure (0 points for a secure knot, 10 points for a slipping knot, and 20 points for a knot that came apart) (Figs. 6, 7, and 8).

Statistics

The baseline was compared with the final score for each task in vivo by paired *t*-test for group A and group B. Linear regression analysis was used to test for correlation between in vivo and in vitro scores for each task and for the total score (sum of all scores).





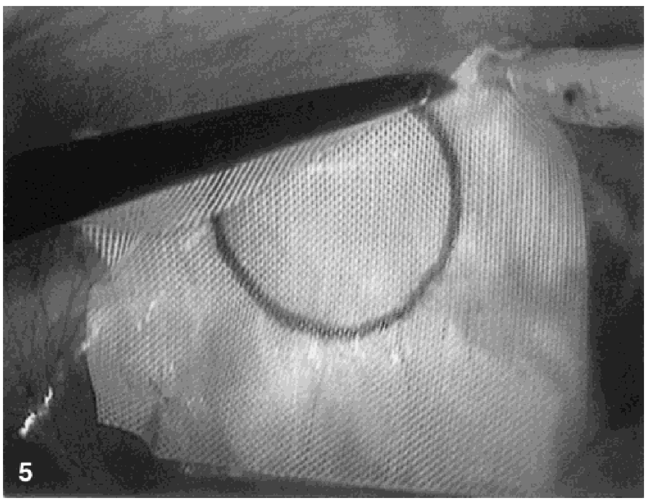


Fig. 1. Transferring.

Fig. 2. Cutting.

Fig. 3. Clip application.

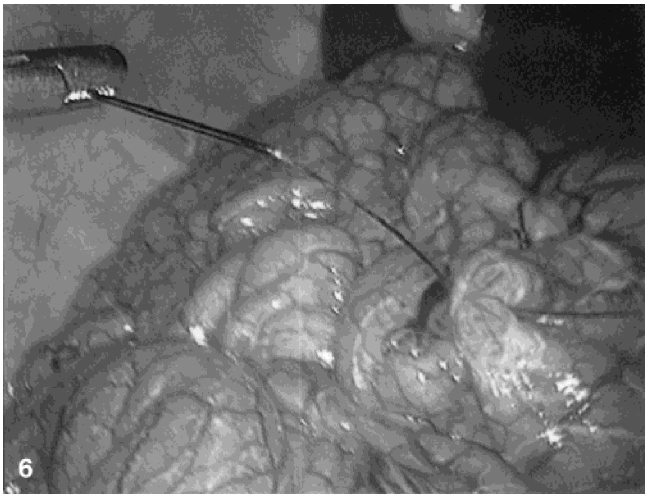
Fig. 4. Placement of ligating loop.

Fig. 5. Mesh placement over a defect.

Results

Scores measured in the live animal model correlated highly with scores obtained for comparable tasks in the inanimate model, with the exception of the skills involving placement of the ligating loop and securing the mesh. The task with the highest correlation was suturing with an extracorporeal knot ($r = 0.75$; $p = 0.0001$) (Table 2). The sum of the scores for all seven tasks (total score) in the inanimate model and in the pig correlated very highly ($r = 0.76$; $p = 0.0001$) (Fig. 9).

Residents who had structured weekly practice sessions in the MISTELS program demonstrated improved performance from baseline to final evaluation for all skills measured in vivo, except for needle transferring and placement of the ligating loop. Its contrast, improvement in residents without practice was significant only for the suturing skills (Table 1). The final total score for residents who practiced increased to 248 ± 53% of baseline ($p = 0.02$) compared with 135 ± 15% of baseline ($p = 0.03$) for those without practice. This difference was significant ($p < 0.05$).



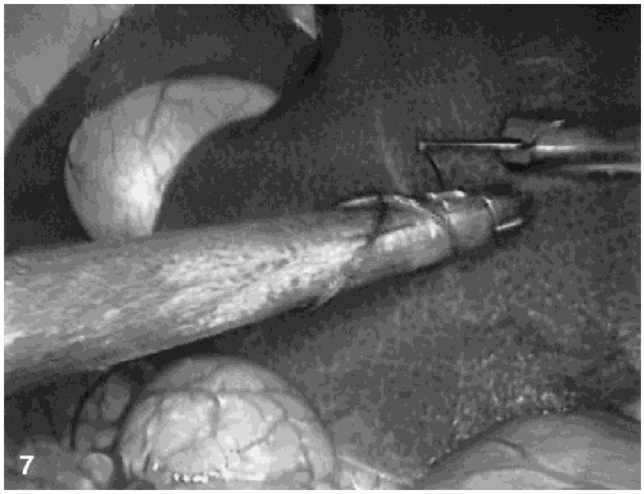


Fig. 6. Placement of suture.

Fig. 7. Intracorporeal knot tying.

Fig. 8. Extracorporeal knot tying.

Table 1. Baseline and final in vivo scores for group A (with practice) and group B (with no practice)[a]

Task	Transfer	Cutting	Clipping	Looping	Placing mesh	IC	EC	Total score
Group A								
Baseline	141 ± 14	38 ± 13	66 ± 29	92 ± 31	165 ± 55	178 ± 69	136 ± 44	796 ± 184
Final	154 ± 29	143 ± 50[b]	173 ± 7[b]	141 ± 34	264 ± 53[b]	333 ± 49[b]	197 ± 48[b]	1514 ± 190[b]
Group B								
Baseline	154 ± 16	46 ± 29	136 ± 4	157 ± 21	172 ± 36	243 ± 48	155 ± 36	1063 ± 125
Final	174 ± 7	97 ± 34	143 ± 12	136 ± 33	228 ± 63	328 ± 45[b]	277 ± 15[b]	1383 ± 130[b]

[a] Mean ± standard error of mean (SEM)
[b] Final score superior to baseline score within each group ($p < 0.05$)
IC, intracorporeal knot; EC, extracorporeal knot

Discussion

Laparoscopic surgical training has evolved from programs designed for experienced surgeons to those for residents at a more junior level. Therefore, tailoring laparoscopic practice to train junior level residents effectively and efficiently is of paramount importance. Melvin et al. [5] developed a curriculum in which junior residents learn laparoscopic knot tying and suturing through dirrect vision and the use of a laparoscopic camera. Mori et al. [6] looked at the basic components of laparoscopic suturing and knot tying (needle mounting, needle driving, and knot tying). Their program of 3 half days included in vitro and live animal training. The basic laparoscopic skills were evaluated at different times during the course, and it was found overall that needle mounting and knot tying skills improved significantly and the time required decreased by nearly half at the end of the course as compared with observations at the beginning. These authors concluded that laparoscopic skills requiring two-hand coordination can be taught efficiently in a skill development course, and that these skills can be improved significantly by hands-on training.

Simulator training is simple, inexpensive, and portable, requiring minimal instruction. It allows for practice at various levels. Animal laboratory training is believed by many to be required for any training course in laparoscopic cho-

Table 2. Correlation coefficients of in vitro and in vivo scores

	Tasks							
	1	2	3	4	5	6	7	Total score
r	0.47	0.66	0.48	0.15	0.31	0.50	0.75	0.76
p	0.02	0.0005	0.02	0.50	0.14	0.01	0.0001	0.0001

Table 2 summarizes the correlation coefficients and *p* values of the comparison of in vivo scores with in vitro scores for each task. Significant correlation was found for the total score and scores for all tasks except 4 and 5

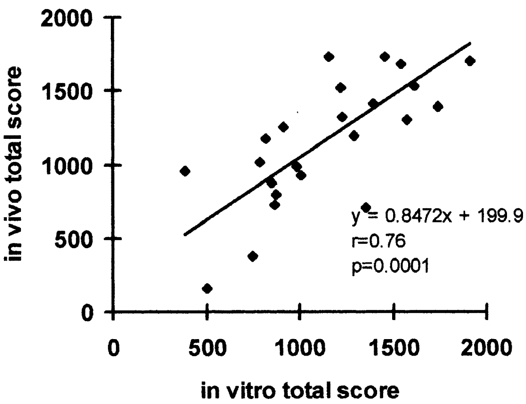


Fig. 9. Correlation of in vivo total scores with in vitro total scores (correlation coefficient $r = 0.76$; $p = 0.0001$).

lecystectomy [1]. However, animal laboratory facilities may not be accessible to all. Using animals to practice surgical skills is prohibited in Great Britain. If performance in an inanimate model is equivalent to performance in live animals, the use of such simulator models would be validated. Martin et al. [4] compared their open surgical bench models with performance of similar tasks in live anesthetized animals. Their correlations between scores on bench and live examinations were high, validating their bench models.

Studies have looked at methods for enhancing and evaluating laparoscopic skills [2, 3, 5–7, 9, 11, 12]. However no reports in the literature have compared comparable skills in an in vivo model, thus further validating simulator performance. The purpose of this study was to evaluate how practice in the laparoscopic simulator can affect performance in an animal model, and to correlate performance in the simulator with performance in the animal model for specific basic laparoscopic tasks.

In comparisons of baseline scores with final in vivo scores, group A showed a significant improvement in five of seven tasks (cutting, clipping, mesh placement, intracorporeal and extracorporeal knot tying) and in the total score. Group B improved significantly only in two of seven tasks (intracorporeal and extracorporeal knot tying) and in the total score. Interestingly, intracorporeal and extracorporeal suturing improved both in the group with practice and in the group with only one repetition. Correlations of the simulator scores with scores in the porcine model for each task showed a significant correlation for all tasks except the placement of the ligating loop and placement of the mesh (Table 2).

The total score (sum of all the scores) for the simulator significantly correlated with the total score for the animal model. Therefore, overall there was good correlation between the two models, indicating that they were both measuring similar laparoscopic skills. Correlation of scores for the two models further validates the simulator as a tool for assessing laparoscopic skills. Construct validity was previously demonstrated in the McGill Laparoscopic Simulation Study, in which statistically significant improvement in performance with increasing level of training was seen with most tasks [3]. Further studies will evaluate face validity by correlating simulator performance with in vivo performance in the operating room.

Acknowledgment. This work was supported by an educational grant from the United States Surgical Corporation (Auto Suture Canada).

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