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A method of objectively evaluating improvements in laparoscopic skills

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Abstract
Background: In this paper, we explored a quick and inexpensive method to evaluate the improvement in laparoscopic skills gained by residents after attending a formal training course in laparoscopy.
Methods: Surgical residents attending an endoscopic workshop were randomly selected to perform tasks in a training simulator. Each was evaluated qualitatively and quantitatively before and after the workshop. A control group of six residents who did not attend the workshop were selected to perform the same tasks twice in succession.
Results: The total mean time improvement for all tasks in the study group was 34.3% and in the control group 7.3% ($p = 0.0001$). When the data was separated for each task, statistically significant improvement was demonstrated in five of the six tasks.
Conclusions: Residents who attend a formal workshop in endoscopy can gain significant improvement in skills. The methods described in this study can be used to quantitatively measure this improvement throughout a resident's training.

Key words: Laparoscopic surgery — Education — Evaluation — Learning curve

Laparoscopic surgery is a relatively new addition to the armamentarium of general surgeons in the United States. Its application to traditional surgical problems continues to expand. Laparoscopic cholecystectomy (LC), for example, is a very common procedure that has rapidly become the ‘‘gold standard’’ for treatment of gallstone disease since its introduction to the United States in 1988 [20]. Consequently, open cholecystectomies are now generally performed less frequently and usually reserved for complicated cases or conversion from LC. Laparoscopy is also now widely utilized for diagnostic procedures, appendectomy, herniorrhaphy, bile duct exploration, colon resection, Nissen fundoplication, and peptic ulcer disease [18]. Successful laparoscopic splenectomies, adrenalectomies [18], nephrectomies [3], and small-bowel resection and anastomosis [17] have also been reported.

Unlike most open procedures, however, laparoscopy requires a number of skills that cannot be simply taught by ‘‘apprenticeship’’ due to a shortage of experienced teachers and because of the nature of the skills. It requires the ability to transfer a two-dimensional image into a three-dimensional setting in one's mind, and, consequently, the ability to appreciate depth perception using very subtle visual clues. This requires fine motor skills and hand–eye coordination to manipulate small tools that on-screen move in a direction opposite the controlling hand. What made one a good technical surgeon in the past may not apply in these cases. Visualization of the anatomy is often improved in laparoscopy, but tactile sense is diminished. These aspects of laparoscopic surgery have created a challenge in the training and evaluation of residents.

Recognizing the growing role of laparoscopy in modern surgery, residency programs have rapidly incorporated it into their training regimen. Although there is no consensus on the best methods of teaching laparoscopy, various authors have published some guidelines for formal training courses [9, 15, 16]. Ideally, practicing laparoscopic procedures on animals (such as pigs) would be the most effective method of gaining real surgical experience before operating on patients, but such methods have yet to be widely adopted by residency programs, mainly due to cost and issues of appropriate animal use [13]. The question that is often raised, by both surgeons and the public, is whether these training sessions are effective in actually improving one's skills enough to become proficient at performing laparoscopic surgery [14, 16]. Therefore, it is important to be able to objectively evaluate the improvements gained by surgeons after attending a training course. The Society of American Gastrointestinal Endoscopic Surgeons (SAGES) describes the use of pre- and post-testing in the evaluation of training courses and the trainees [15]. They are defined as ‘‘a quantifiable examination of a trainee's level of clinical knowledge, manual skills or technical proficiency prior to

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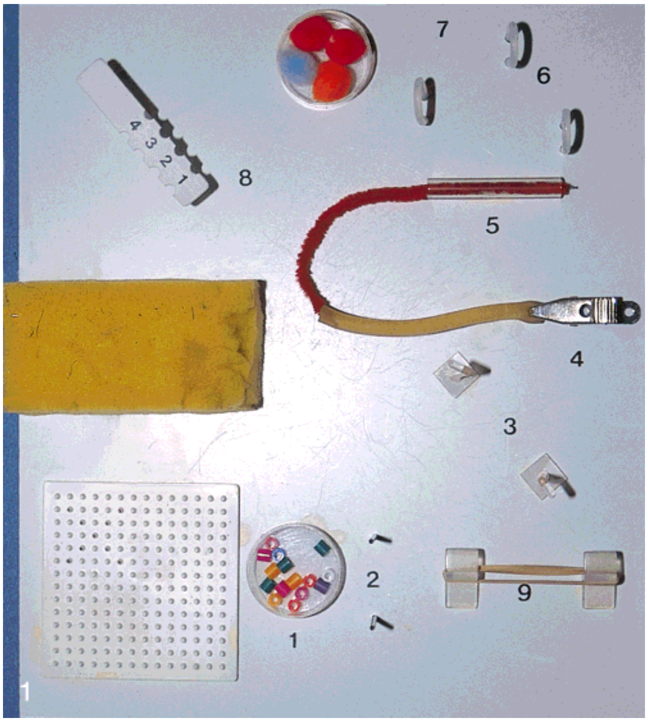

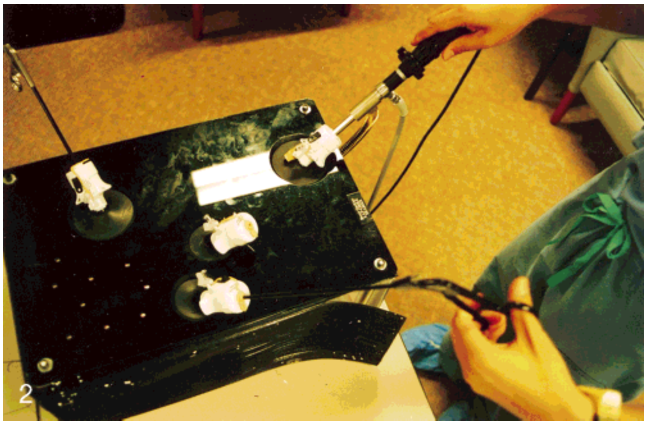

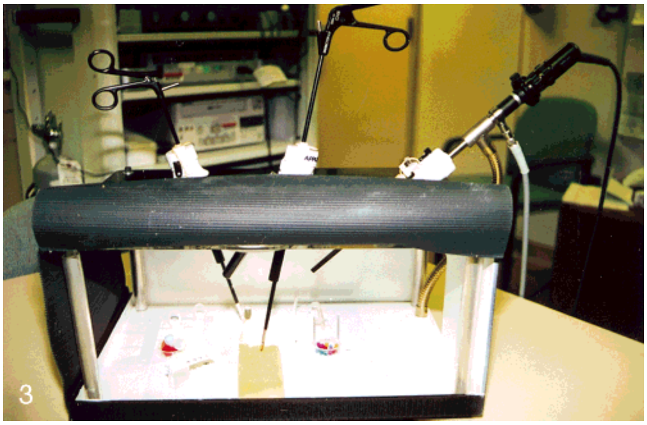

Fig. 1. Skills practice board on which the six tasks are performed.

Fig. 2. Training box developed to simulate endoscopic procedures.

Fig. 3. Training box with endoscope and instruments.

commencing a training course'' and ''upon completion of a training course.'' However, exact methods are not specified and are left to the discretion of individual institutions.

Laparoscopic surgery is still in its early stages of development. New methods of training are being developed, and there is a need to establish a standardized method to objectively evaluate skills. In this paper, we explore an inexpensive and easy method of objective evaluation and test it on residents who attend a training workshop.

Materials and methods

The first part of the data was collected at the two-day Endoscopy Workshop for Surgical Residents (courtesy of Ethicon Endosurgery Inc., Cincinnati, Ohio) organized by SAGES on January 13–14, 1995. The workshop included 4 h of lectures, 2 h of laparoscopic skills practice in inanimate models (a skills board held within a training box, as used for this study), and 2 h of flexible gastrointestinal endoscopy on live dogs on day 1. On the 2nd day, there were 4 h of lectures followed by 4 h of laparoscopic procedures consisting of LC, Nissen fundoplication, and partial colectomy on live pigs.

Ten residents were randomly selected to perform a battery of six tasks on a skills practice board provided by Ethicon (Fig. 1). Due to a strict time schedule imposed by the training course, it was not possible to enroll a larger number of subjects for the study. Two residents in the study group who did not complete more than half the tasks (due to the above time limitations) were omitted. The study group included two postgraduate year (PGY)-5s, four PGY-4s, one PGY-3, and one PGY-2. The board was placed in a black training box that is fitted with rubber gaskets to accommodate cannulas for the scope and tools (Figs. 2 and 3) [10]. As in conventional LC, the usual fiber-optic light source and camera equipment were used, and the image was displayed on a video monitor. Each participant was given a list of tasks to perform (Table 1, Figs. 4–9).

Table 1. Instructions for study participants

Tasks for objective testing of laparoscopic skills

1. Using one hand only, make an ''X'' shape on the marked pegs on the peg board with 9 pieces (Fig. 4).
2. Using one hand only, transfer the 9 pieces from the ''X'' and place them on the poles, alternating between the poles (Fig. 5).
3. Place two clips on the marked lines on the rubber band; then cut between them (Fig. 6).
4. Without removing it from the glass tube, thread the pipe cleaner into the rubber tube up to the black thread (Fig. 7).
5. Pick up a green ball and pass it through the three loops in succession using both hands; then reverse direction through the loops, returning the ball in the bin (Fig. 8).
6. Suture drill: ''Repair'' the incision on the foam stomach with a single suture. Make two extracorporeal knots and secure each knot with the knot pusher. Cut off the extra suture to a short length (Fig. 9).

Each resident was asked to perform these tasks before beginning the afternoon laboratory on day 1. They were evaluated quantitatively by timing the successful completion of each test. Timing began when the resident placed the first tool into the cannula and ended when the task was complete. After the residents had completed all sessions of the workshop, including the pig lab, they were asked to perform the same tasks and were timed and evaluated in the same manner. Care was taken to simulate the same environment as the first run, such as use of the same equipment and the same assistant to control the camera. All residents used identical tools supplied by Ethicon, including disposable trocars and cannulas, small grasper, needle holder, scissors, knot pusher, disposable clip applier, and 3-0 silk sutures. The residents were allowed to use different ports or stand in different positions during the second run, since the ability to choose the right port or position was considered a skill learned during the workshop.

The second part of the data was collected at the University of California, San Diego Medical Center Thornton Hospital in La Jolla, California.

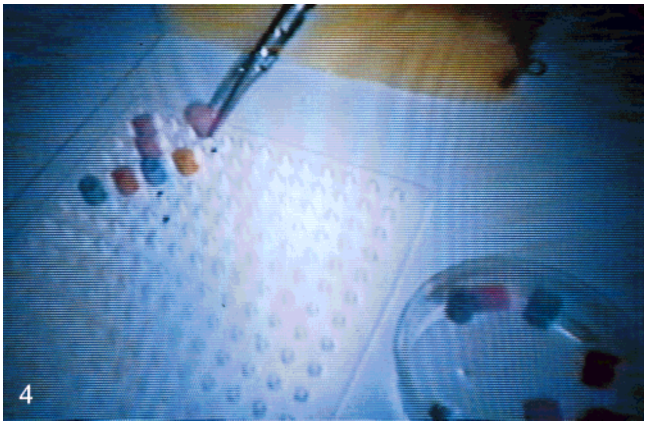

Fig. 4. Peg board and pegs.

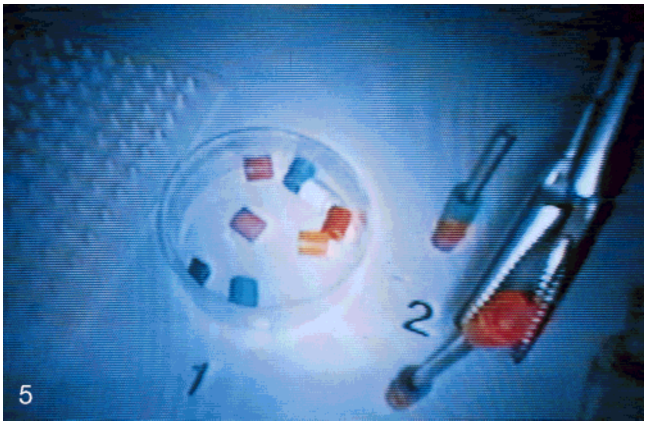

Fig. 5. Pegs being placed on poles.

Fig. 6. Clips being placed on rubberband.

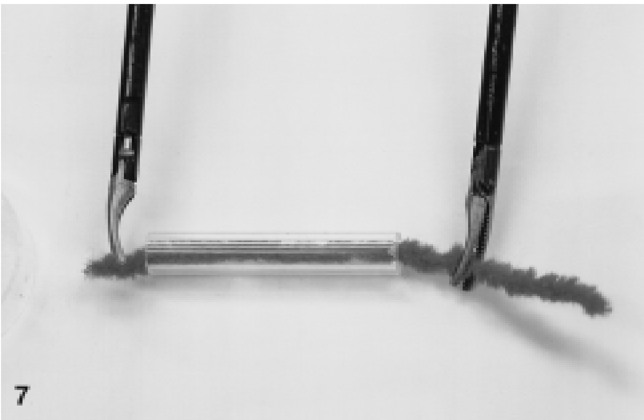

Fig. 7. Threading pipe cleaner into rubber tube.

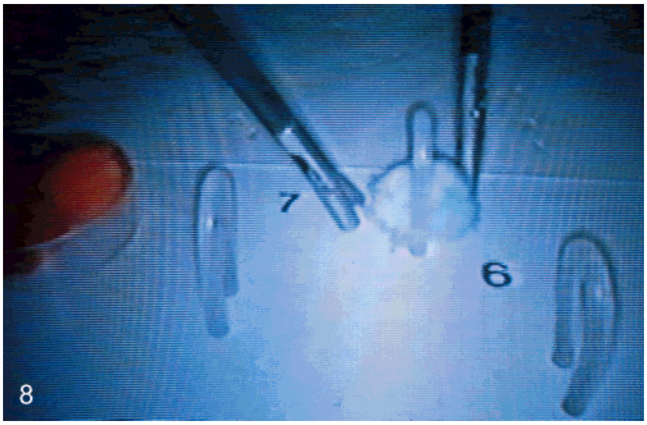

Fig. 8. Passing ball through hoops.

Fig. 9. Suture drill.

A control group of six PGY-5 general surgery residents who did not attend the workshop were asked to perform two runs of the same six tasks. This was to measure any improvement in skills gained simply by performing a task twice. The skills board, laparoscopic equipment, and method of evaluation used for the control group were identical to those of the study group. The difference in the times of the study group before and after the workshop was compared with the difference in the times of the control group at UCSD, and any significant discrepancy between the two groups was interpreted as an improvement in skills attributable to having attended the workshop.

For each task completed by members of both the study group and control group, the difference in times between the second and first runs was calculated and interpreted as an improvement as a percentage of the initial time. Henceforth, the ‘‘improvement’’ will be reported as a percentage value to reflect how much the individual improved on the second try. Student’s *t*-test was used to compare the study and control groups, and a *p* value of <0.05 was considered statistically significant. The data was analyzed using StatViewII (Abacus Concepts, Inc., Berkeley, CA) on a Macintosh computer. The graphics were created with Cricket Graph III (Computer Associates International, Inc., Islandia, NY).

Results

The mean percentage improvements in time for the study and control groups stratified by task are listed in Table 2.

Table 2. Percent mean improvement in time by task (with 95% CI)

Task	Study	Control	*p*
1	26.3 ± 13.9	15.6 ± 21.2	0.11
2	33.4 ± 7.4	19.2 ± 25.7	0.003
3	41.2 ± 14.8	13.2 ± 17.6	0.003
4	38.3 ± 19.3	−21.6 ± 43.8	0.0002
5	31.7 ± 26.2	4.8 ± 14.5	0.045
6	34.7 ± 7.4	12.5 ± 25.0	0.0003
Total	34.3 ± 5.7	7.3 ± 9.2	0.0001

The actual times for each resident for each task are listed in Tables 3 and 4 for the study and control groups, respectively. Six of the eight residents in the study group completed all six tasks, and the remaining two completed five tasks. (They could not complete the second try for one of the tasks in the time allotted by the workshop personnel for this study.) This resulted in a total of 46 tests completed. The mean percentage improvement in time for these tests was 34.3 (range −28.57–78.4) with a 95% confidence interval of ±5.7. Each member of the control group completed all six tasks, resulting in a total of 36 tests completed. The mean percentage improvement in time for these tests was 7.3% (range −100–58.5) with a 95% confidence interval of ±9.2. The improvements of the two groups were significantly different ($p = 0.0001$). The improvement in time observed in the control group (7.3%) is not significantly different from zero percent ($p = 0.12$). When the data was stratified by task, the improvements for each task in the study group were significantly different from control (except for task #1, $p = 0.11$). The mean improvement for all six tasks per resident in the study group ranged from 28.3% to 45.2% and in the control group ranged from −1.1% to 18.5%.

The data for the control group included one unusually low value for task #4 (Table 2). This was mainly the result of one resident who took twice as long to perform the task on the second run (from 1.33 min to 2.67 min), which is a −100% improvement. Considering the short time periods being measured, this is not an unexpected occurrence. Even brief distractions or mistakes that increase the time by several seconds can greatly affect the percentage value. (In this particular instance, the resident bent the pipe cleaner while pushing it into the rubber tube and spent a considerable amount of time straightening it.) We can determine if this value is an outlier and if its omission will affect the data. Using Dixon's analysis of extreme values [4], this value can be defined as an outlier with 95% confidence. Omission of this value yields a mean improvement of −5.9 (±22.6)% for task #4 and an overall mean improvement of 10.3 (±6.9)% for all tasks. The difference between the study group and the new mean for the control is still statistically significant ($p = 0.0001$). Therefore, omission of the outlying value does not affect the outcome of this study.

Discussion

It is not surprising that surgeons improve their skills after attending a training workshop like the one described in this study. After all, that is the intention of training courses. However, we were successful in showing that this improvement can be quantitatively measured using an objective method of testing specific skills. This type of evaluation should be an important component of formal training courses because it provides useful information about both the trainee and the training course. We demonstrated that those who attended the SAGES workshop showed a significantly greater improvement in a variety of basic skills necessary for laparoscopy than those who did not attend the workshop. In addition, attending formal training courses has been shown to be a predictive factor in decreasing complications associated with laparoscopic procedures [14]. This suggests that these courses can help surgeons become more experienced and proficient in laparoscopic surgery.

Not all the tasks in this study were meant to simulate actual surgical techniques. Most were designed to emphasize basic concepts and provide exercises to practice specific skills. The most ideal method of gaining real operative experience outside the operating room would be practicing complete procedures like LC or Nissen fundoplication on live animals such as the domestic swine [6], but this is costly and requires an experienced staff of an anesthetist, a veterinarian, and a lab technician. The advantages of a skills board for objective evaluation of basic skills are twofold. First, the scenario for testing is easily reproducible. The performance is not biased by the variations in anatomy or physiologic response found in animals. The exact same test can be repeatedly administered in identical fashion at any location, at any time. Second, the equipment is inexpensive, reusable, and easy to set up quickly without an experienced staff.

One specific operative skill that we tested was the ability to place a suture and make an extracorporeal knot (task #6). Using sutures to approximate tissue in laparoscopic procedures can be very difficult and time consuming. Most surgeons are quick to use clips to ligate the cystic artery and duct during an LC, for example, but bile leakage from a slipped cystic duct clip [1] and common bile duct injury from improper clipping [12] have been reported as complications. Thus, surgeons should always be prepared for the unexpected need to use sutures in situations where clips fail. In addition, as the application of laparoscopy expands to include more complex procedures, suturing and knot-tying on a video screen will be an important part of surgery in the future [19]. For these reasons, it is important for all surgeons to become comfortable with laparoscopic suturing and tying techniques. In task #6, the residents were asked to place a single stitch on a ‘‘laceration’’ on a foam stomach model using 3-0 silk suture on a curved tapered needle. They formed a standard surgeon's knot extracorporeally and used a knot pusher to secure the knot. Though not specifically timed, it was observed that the most difficult and time-consuming maneuver was finding the appropriate needle position to take adequate bites. The residents in the study group demonstrated significant improvement in suturing and tying compared to control. This is probably attributable to the amount of practice and training received during the workshop. A variety of instruments and methods of facilitating suture techniques have been previously described [12]. These could easily be incorporated into a testing regimen and used for objective evaluation as well.

It is not clear exactly why the difference in the improvement in task #1 was not statistically significant. One pos-

Table 3. Times (in minutes) and percent improvements in the study group

		Study group participants								
Task	Run	1	2	3	4	5	6	7	8	Mean
1	1	3.37	6.42	3.93	4.37	4.17	5.60	3.53	8.62	5.00
	2	3.13	4.22	3.07	3.27	3.42	3.15	3.30	4.03	3.45
	Difference	0.23	2.20	0.87	1.10	0.75	2.45	0.23	4.58	1.55
	% Diff.	6.93	34.29	22.03	25.19	18.00	43.75	6.60	53.19	26.25
2	1	3.73	8.13	1.47	2.78		2.15	1.97	3.73	3.42
	2	2.57	6.17	1.05	1.83		1.13	1.17	2.68	2.37
	Difference	1.17	1.97	0.42	0.95		1.02	0.80	1.05	1.05
	% Diff.	31.25	24.18	28.41	34.13		47.29	40.68	28.13	33.44
3	1	2.90	2.08	1.83	1.00	2.03	0.92	1.02	2.68	1.81
	2	1.23	1.75	1.33	0.58	0.60	0.58	0.72	1.32	1.01
	Difference	1.67	0.33	0.50	0.42	1.43	0.33	0.30	1.37	0.79
	% Diff.	57.47	16.00	27.27	41.67	70.49	36.36	29.51	50.93	41.21
4	1	5.15	4.00	3.38	2.52	5.43	1.53	3.32	4.55	4.05
	2	2.17	2.18	1.73	1.32	4.28	1.72	1.87	2.12	2.24
	Difference	2.98	1.82	1.65	1.20	1.15	−0.18	1.45	2.43	1.81
	% Diff.	57.93	45.42	48.77	47.68	21.17	−11.96	43.72	53.48	38.28
5	1	1.17	6.57	2.85	2.32	7.72	2.17	3.10	2.52	3.89
	2	1.50	3.70	1.20	1.60	1.67	1.68	2.48	1.78	2.02
	Difference	−0.33	2.87	1.65	0.72	6.05	0.48	0.62	0.73	1.87
	% Diff.	−28.57	43.65	57.89	30.94	78.40	22.31	19.89	29.14	31.71
6	1	7.67		6.07	8.52	8.28	4.43	4.75	6.78	6.64
	2	4.22		4.93	5.48	5.15	2.88	3.18	4.22	4.30
	Difference	3.45		1.13	3.03	3.13	1.55	1.57	2.57	2.35
	%Diff.	45.00		18.68	35.62	37.83	34.96	32.98	37.84	34.70
Mean individual percent improvement		28.33	32.71	33.84	35.87	45.18	28.79	28.90	42.12	34.26

Table 4. Times (in minutes) and percent improvements in the control group

		Control group participants						
Task	Run	1	2	3	4	5	6	Mean
1	1	2.48	2.53	3.30	3.28	3.33	3.85	3.13
	2	2.65	2.37	2.03	3.08	1.90	3.62	2.61
	Difference	−0.17	0.17	1.27	0.20	1.43	0.23	0.52
	% Diff.	−6.71	6.58	38.38	6.09	43.00	5.97	15.55
2	1	2.12	3.85	4.35	2.53	3.90	4.25	3.50
	2	1.82	3.45	2.00	2.95	2.38	3.64	2.71
	Difference	0.30	0.40	2.35	−0.42	1.52	0.61	0.79
	% Diff.	14.17	10.39	54.02	−16.45	38.89	14.35	19.23
3	1	1.25	1.42	0.88	0.78	0.75	1.12	1.03
	2	1.37	1.22	0.78	0.45	0.65	1.04	0.92
	Difference	−0.12	0.20	0.10	0.33	0.10	0.08	0.12
	% Diff.	−9.33	14.12	11.32	42.55	13.33	7.14	13.19
4	1	1.08	1.80	1.33	1.73	1.53	2.48	1.66
	2	1.05	2.20	2.67	2.13	1.65	1.98	1.95
	Difference	0.03	−0.40	−1.33	−0.40	−0.12	0.50	−0.29
	% Diff.	3.08	−22.22	−100.00	−23.08	−7.61	20.16	−21.61
5	1	1.38	1.08	0.92	0.67	1.20	1.79	1.17
	2	1.40	1.22	0.82	0.60	0.88	1.88	1.13
	Difference	−0.02	−0.13	0.10	0.07	0.32	−0.09	0.04
	% Diff.	−1.20	−12.31	10.91	10.00	26.39	−5.03	4.79
6	1	6.78	4.67	3.42	6.50	3.87	7.88	5.52
	2	7.22	4.62	2.98	2.70	3.98	6.94	4.74
	Difference	−0.43	0.05	0.43	3.80	−0.12	0.94	0.78
	% Diff.	−6.39	1.07	12.68	58.46	−3.02	11.93	12.46
Mean individual percent improvement		−1.06	−0.40	4.55	12.93	18.50	9.09	7.27

sible explanation is that the task may not have been very difficult for some of the residents, and thus, there was less potential for improvement compared to more difficult tasks. This task was designed to test basic skills, such as depth perception and grasping small objects using only one hand. Another possibility is that the workshop did not improve these particular skills as much as more complex skills such as two-handed coordination and suturing.

There were a few limitations that could not be avoided in this study. The two groups used different video equipment provided by the respective institutions. However, we did not encounter any problems with the equipment at either location, and the video resolution was excellent on all monitors. One potential problem is that we had a limited amount of time to conduct the study in Cincinnati. Consequently, the hurried environment may have made the residents nervous. However, they were instructed to perform each task deliberately, as they would in real surgery. In contrast, the residents in the control group were tested individually at convenient times, so they were not rushed. Although we cannot draw any specific conclusions on the effects of these factors on the data, we suspect they probably did not create any bias significant enough to alter the outcome of this study.

The tasks described in this study were used to demonstrate improvement in skills after attending a training course. This method of skills evaluation could conceivably have other applications for a variety of situations in a surgery training program. Pre- and post-testing are vital components in postresidency surgical training, as outlined by SAGES [15], for the purpose of assessing individual improvement as well as the overall effectiveness of the training course. In addition, the pre-test could assess a trainee's skill level to customize the training session to focus on individual areas of deficiency. The same concept could be adapted to maximize individual training in residency programs.

A quantitative evaluation in the form of standardized tests could potentially be useful in following residents' progress at their home institutions. For example, a set of tasks on a skills board could be included as part of resident examinations to make sure residents have reached a certain skill level before attempting techniques in the operating room. In other words, residents would not be allowed to operate on patients until they have demonstrated proficiency at certain basic laparoscopic skills. Each resident's performance on the tasks would be evaluated qualitatively by an experienced surgeon. In addition, the residents would be required to complete the tasks within an ''acceptable'' time limit. Although speed may not necessarily equate proficiency, it can be related to familiarity with the equipment and confidence in the procedure and results in faster operative time [4]. Decreased operative time is a measure of the laparoscopic learning curve in many reports [4, 5, 8, 11] and is generally a desirable goal in terms of minimizing cost and complications associated with prolonged operations or with prolonged pneumoperitoneum [2, 7].

Conclusions

As laparoscopy continues to expand, it is important that we strive for the best patient care while exploring new, innovative uses of its technology. Formal training courses in laparoscopy can improve basic skills and provide practice for surgeons in training. An objective and quantitative method of evaluation should be a necessary part of these training courses and can be useful in assessing individual improvement after training programs. We present a method in this paper that is inexpensive and easy to set up and provides a quantitative measurement of operative skills. With further development, this concept may be adapted for following the progress of residents during their years in training or developing a set of standardized tests that surgeons must pass to exhibit proficiency in operative skills.

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