RANDOMIZED CLINICAL TRIAL

A Comparison of 2 Ex Vivo Training Curricula for Advanced Laparoscopic Skills

A Randomized Controlled Trial

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Objective: To compare the effectiveness and cost of 2 ex vivo training curricula for laparoscopic suturing.

Background: Although simulators have been developed to teach laparoscopic suturing, a barrier to their wide implementation in training programs is a lack of knowledge regarding their relative training benefit and their associated cost.

Method: This prospective single-blinded randomized trial allocated 24 surgical residents to train to proficiency using either a virtual reality (VR) simulator or box trainer. All residents then placed intracorporeal laparoscopic stitches during a Nissen fundoplication on a patient. The operating room (OR) cases were video-recorded and technical proficiency was assessed using 2 validated tools. OR performance of both groups was compared to that of conventionally trained residents and to fellowship-trained surgeons. A cost analysis of box training, VR training, and conventional residency training across Canadian surgical programs was performed.

Results: After ex vivo training, no significant differences in laparoscopic suturing in the OR were found between the 2 groups with respect to time ($P = 0.74$)—global rating score ($P = 0.65$) or checklist score ($P = 0.97$). It took conventionally trained residents 6 practice attempts in the OR to achieve the technical proficiency of the ex vivo trained groups ($P = 0.83$). VR training was more efficient than box training (transfer effectiveness ratio of 2.31 vs 1.13). The annual cost of training 5 residents on the FLS trainer box was $11,975.00, on the VR simulator was $77,500.00, and conventional residency training was $17,380.00. Over 5 years, box training was the most cost-effective option for all programs, and VR training was more cost-effective for programs with more 10 residents.

Conclusions: Training on either a VR simulator or on a box trainer significantly decreased the learning curve necessary to learn laparoscopic suturing. VR training, however, is the more efficient training modality, whereas box training the more cost-effective option.

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Laparoscopic intracorporeal suturing and knot tying are considered some of the most technically demanding minimally invasive skills to acquire. Nonetheless, proficiency in these skills is a requirement for surgeons to perform advanced laparosopy.[1] Studies have demonstrated that technical aptitude in open suturing and knot-tying is not transferable to the laparoscopic technique.[2] Compounding the difficulty inherent in learning this advanced laparoscopic skill are the diminished operative opportunities for surgical residents resulting from work-hour restrictions, and ethical concerns related to trainees learning novel skills on patients.[3,4] As a consequence of these pressures, and the technical demands of minimally invasive surgery, alternative ex vivo training methods have been developed that include laparoscopic box trainers and computer-based virtual reality (VR) simulators.[5]

Several recent systematic reviews have demonstrated that laparoscopic training in an ex vivo environment, whether on a bench-top model or a VR simulator, translates into an improvement in operating room performance.[6–9] The studies examined in these reviews, however, largely examine the acquisition of basic laparoscopic skills. The group of studies investigating the teaching of advanced laparoscopic skills, such as laparoscopic suturing, is much smaller; although, as a group they largely support these simulators as training modalities.[10–16] These studies, however, are methodologically diverse. In certain cases, the groups are not randomized or the assessors are not blinded.[11,13] In addition, many of these studies report preliminary work where the outcome measures are assessed in the surgical skills laboratory rather than in the operating room.[10–13] Assessing transferability to the operating room is essential to justify the significant resources required to adopt ex vivo training methods into residency training programs. An exception to this is a recent randomized controlled trial that demonstrated that a curriculum of VR training combined with laparoscopic box training resulted in improved intracorporeal suturing in the operating room.[16] Although this study supports the use of a combined curriculum to teach advanced laparoscopic skills, using both types of simulators in a training program requires a significant amount of investment with respect to expert time and simulator cost. Indeed, the authors state that at the time of publication, the cost of both simulators used in the study was more than $100,000. Moreover, this figure did not include other costs including disposable items, such as sutures, or indirect costs such as expert facilitators. Because of these associated expenses, it is essential to ascertain the relative benefit of both box training and VR on the acquisition of advanced laparoscopy. Currently, no randomized controlled studies have compared box training with VR training in the transferability of laparoscopic suturing to the operating room.

The purpose of this study was therefore threefold. First, we aimed to compare the effectiveness of VR and laparoscopic box training to teach intracorporeal suturing. Specifically this included a comparison of the transferability of the acquired technical skills on both models to an analogous bench-top simulator and to technical performance in the operating room. Second, the skills of the VR-trained and box-trained residents were compared to the technical performance of both experienced laparoscopists and conventionally trained residents in the operating room to assess the relative gains acquired by these 2 modalities of ex vivo training. Finally, a cost

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analysis was performed to assess the relative cost of laparoscopic box training, VR training, or conventional residency training to teach laparoscopic suturing.

METHODS

Study Design

This study was a randomized, prospective, single-blinded trial conducted at a tertiary academic center. The appropriate institutional review boards approved this study and written informed consent was obtained from all participants.

Participants

Twenty-four general surgery residents at the postgraduate year (PGY) 2 level or above, with intermediate laparoscopic surgery experience (performed >10 basic laparoscopic procedures as the primary surgeon) participated in the study. Exclusion criteria included previous formal trainer box or VR laparoscopic suturing training, or participation in a laparoscopic suturing course. The residents were randomized using a closed envelope technique to either a VR training group or a laparoscopic box-trainer group (Fig. 1).

Initial Assessment

After randomization, all participants completed a brief questionnaire designed to assess their demographics and laparoscopic experience to date. All participants then completed the suturing task on the LapSim VR simulator (Surgical Science, Gothenburg, Sweden). This task involves the correct completion of a 3 throw, squared intracorporeal knot. Before the completion of this task, all participants received a standardized orientation to the simulator, and a video demonstration of the required task.

Intervention

Residents randomized to the VR proficiency-based laparoscopic suturing curriculum performed the suturing task on the LapSim at 3 progressive settings of difficulty until proficiency criteria were reached. Progressive difficulty parameters included a smaller area of tissue to suture, a shorter suture, and easily damageable tissue. Participants were able to view and utilize the LapSim's automatically generated performance feedback upon completion of each trial. Proficiency was achieved once residents passed the task on the "hard" setting.

Residents randomized to the laparoscopic box-trainer group received proficiency-based laparoscopic suturing training on the Fundamentals of Laparoscopic Surgery (FLS) box trainer from 1 of 2 MIS surgeons. This group practiced intracorporeal suturing on the box trainer until proficiency was reached. Residents were deemed proficient once they passed the task according to the previously validated FLS scoring metrics, which include time to completion and knot errors.[15,17] The expert surgeon provided individualized feedback after completion of each suturing task. The number of trials and time required to reach proficiency criteria were recorded for all subjects.

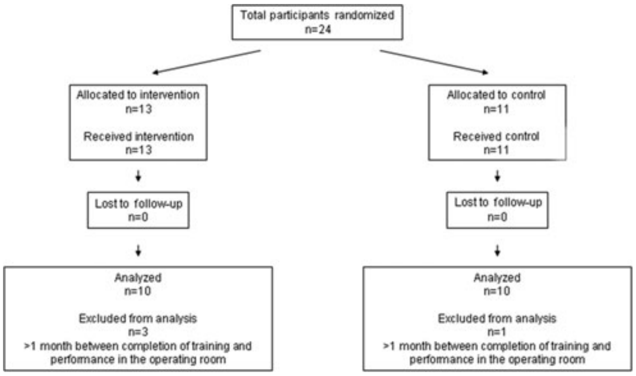

FIGURE 1. CONSORT diagram for study participants.

Final Assessment

Laparoscopic Fundoplication Model

The first aspect of the posttest utilized a laparoscopic Nissen fundoplication model (University of Toronto Surgical Skills Centre, Mount Sinai Hospital). This model is a synthetic esophagus and gastric fundus situated within a box trainer. The test required residents to place 3 interrupted laparoscopic sutures to secure the fundoplication. Trainees used 2.0 Ethibond (Ethicon, Inc) sutures cut at 6 in on a taper CT-2 needle and endoscopic needle drivers (Ethicon Endo-Surgery). Participants' performance was scored live by 1 of 2 expert minimally invasive surgeons using 2 previously validated assessment tools (OSATS global rating scale and procedure-specific checklist).[18,19] Each of the 3 laparoscopic sutures placed on the fundoplication model were scored independently. The assessors were blinded to the randomization of the residents.

Intraoperative Performance

The intraoperative component of the posttest required participants from both training groups to place intracorporeal laparoscopic stitches during a Nissen fundoplication on a patient. This occurred less than 10 days after the last training session on the relevant simulator. The supervising surgeons were blinded to the randomization status of the residents. Each resident performed 3 interrupted, 3-throw, squared, laparoscopic sutures using Ethicon endoscopic needle drivers and 2.0 Ethibond sutures cut at 6 inches on a taper CT-2 needle. The procedure was recorded through the laparoscopic camera. A blinded expert reviewer assessed the intraoperative performance using the procedure-specific checklist and global rating scale.

To compare the performance of the residents in the study with conventionally trained residents and expert surgeons, 6 senior general surgical residents, and 3 fellowship-trained minimally invasive surgeons were recruited. These participants also performed interrupted 3-throw squared sutures during a laparoscopic Nissen fundoplication. Unlike residents in the randomized controlled portion of the study who only performed 3 sutures, these participants completed at least 2 procedures where they performed the suturing of the wrap. These surgeries were recorded through the laparoscopic camera. A blinded expert reviewer assessed the quality of the sutures using the procedure-specific checklist and global rating scale.

Outcome Measures

The primary outcome measure for the study was the difference in operating room performance between the VR and box-trainer groups. Secondary outcome measures include the transfer effectiveness ratio values for the 2 groups, and a comparison of the learning curves for each training group. Finally, another secondary outcome measure included a comparison of the performance of the 2 suturing training groups in the operating room to the performance of conventionally trained residents and fellowship-trained surgeons in similar circumstances.

Sample Size Calculation

A power calculation was performed to assess the number of participants required in the VR and box-trainer groups. Previous work comparing intermediate to novice performance in intracorporeal suturing shows an effect size of approximately 1.3.[18] For the purposes of this study, this difference in performance was deemed to be the minimum relevant difference required to differentiate between these 2 ex vivo teaching modalities. Using an alpha of 0.05 and a power of 0.80, the minimum number of participants in each group was 9.

Statistical Analysis

Descriptive statistics were calculated for all variables. Data is reported as median (interquartile range). Variables were not normally distributed; therefore, differences between the VR and FLS group on the Nissen fundoplication model and in the operating room were assessed using the Mann-Whitney *U* test. In addition, further analysis in the operating room between the 4 groups in the study (VR-trained, FLS-trained, conventionally trained, and expert-trained groups) was performed with the Kruskal-Wallis test. Finally, Friedman's test was utilized to examine the learning curve of the conventionally trained residents in the operating room. The transfer effectiveness ratio (TER) of the VR- and FLS-trained residents was calculated using methods previously described by Aggarwal et al.[20] Briefly, the following equation was used: $\text{TER} = (Y_0 - Y_X)/X$; where Y_0 is the median time required by the control group to reach performance criterion, and Y_X represents the corresponding measure for the intervention group after having received a median of X amount of time on the relevant simulator. All statistical analysis was performed using SPSS Version 16 (SPSS Inc, Chicago, IL). A $P < 0.05$ was considered statistically significant.

Cost Analysis

The annual costs of materials for the laparoscopic box trainer and the VR simulator were obtained from the relevant manufacturer (LapSim, Surgical Science, Sweden, and Ethicon, Johnson & Johnson, Markham, Canada). The cost of conventional resident training to learn laparoscopic suturing was determined by adding the cost of OR time, which was estimated to be $800.00/hr, the cost of a surgeon's time, and the cost of an anesthetist's time (Table 1). Estimates of these costs were obtained from the Ontario Medical Association and from communications with the Financing Department, Division of Budgets and Special Projects at St Michael's Hospital, Toronto, Canada. To assess how costs changed over time, estimates were made regarding the cost of purchasing new materials over both a 1-year and a 5-year period (Table 1). Finally, to assess differences in cost relating to program size, the size of Canadian residency general surgical programs were obtained from the 2009 match data from the Canadian Resident Matching Service (CaRMS) Web site.[21]

RESULTS

Twenty-four surgical residents participated in the randomized controlled portion of the study. Four subjects were excluded from analysis (3 from the box-trainer group and 1 from the VR group) because there was an extended period of time (>1 month) between the completion of training and the ability to perform in the operating room. The median PGY in the VR and box-trainer groups were 3.2 and 2.6 years, respectively. The median PGY level in the control group was 4.0. Laparoscopic experience was similar in both groups with residents in the VR group reporting a median of 20 (10–40) laparoscopic cases versus a median of 30 (15–40) cases reported by residents in the box-trainer group. Finally, the trainees in both groups reported that they had never performed a laparoscopic suture in the operating room.

Initial Assessment

There was no statistically significant difference in median time between the VR and box-trainer groups during the pretest on the VR simulator [VR group 198s (131–286), box trainer 286s (195–445) ($P = 0.19$)]. Both groups also had similar median economy of movement scores [total path length VR 5.31 m (4.19–10.92), box trainer 6.74 m (4.19–11.54) ($P = 0.45$); total angular path VR 1331Ì (1073–2860), box trainer 1692Ì (1044–3031) ($P = 0.55$)]. Finally the initial error measurements between both groups were similar [maximum tissue damage VR 108 mm (64–145), box trainer 34 mm (12–125) ($P = 0.17$)].

TABLE 1. Associated Costs of 3 Methods of Teaching Laparoscopic Suturing

Training System	Cost Per Year	5 Year Cost
Laparoscopic box trainer		
Trainer box	$2230.00	$2230.00
Suture block	$25.00	$75.00
Penrose drains	$70.00	$210.00
Endoscopic needle drivers (@$1500 each)	$3000.00	$6000.00
Laparoscopic scissors	$1200.00	$2400.00
TV monitor	$500.00	$500.00
Ethibond sutures (average of 5.2 sutures/resident at $5/suture)	$260.00	$1300.00
Surgeon/expert's time (@$469/hr)	$4690.00	$23,450.00
Total box trainer	$11,975.00	$36,165.00
VR training		
LapSim surgical simulator	$54,500.00	$54,500.00
Software licensing/maintenance	—	$2500.00
Haptic interface	$23,000.00	$23,000.00
Total VR trainer	$77,500.00	$80,000.00
Conventional residency training	1 year cost	5 year cost
Cost of OR time ($800/hr × 5 residents)	$8000.00	$40,000.00
Cost of surgeon's time ($469/hr × 5 hrs)	$4690.00	$23,450.00
Cost of anesthesiologist's time ($469/hr × 5 hrs)	$4690.00	$23,450.00
Total conventional training	$17,380.00	$86,900.00

Based on teaching 5 residents.

Intervention

Time Required to Reach Proficiency

Subjects in the VR group reached proficiency with laparoscopic suturing after a median of 17 minutes (13–21), whereas subjects in the box-trainer group reached proficiency after 35 minutes (27–49) ($P < 0.001$).

Final Assessment

Laparoscopic Fundoplication Model

Residents who were trained on the VR simulator were found to be significantly faster than residents trained on the FLS box trainer with respect to the time required to successfully complete the first of 3 laparoscopic sutures performed on the laparoscopic fundoplication model [VR 99 seconds (71–195), box trainer 248 seconds (203–295) ($P = 0.03$)]. There was no significant difference between the 2 groups, however, with respect to the amount of time required to complete the second and third laparoscopic sutures performed on the same model [second VR 175 seconds (106–221), box trainer 160 seconds (146–185) ($P = 0.21$); third VR 143 seconds (94–171) box trainer 154 seconds (138–179) ($P = 0.12$)]. Similarly, there was no statistically significant difference in either global rating scale score or checklist scores between the 2 groups for each of the 3 laparoscopic sutures performed on this model [global rating scale: 1, VR 20(17–25) box trainer 23(21–25) ($P = 0.27$); 2, VR 24(21–24), box trainer

24(24–26) ($P = 0.07$); 3, VR 26(24–26), box trainer 27(24–25) ($P = 0.20$); checklist: 1, VR 24(20–27) box trainer 23(21–26) ($P = 0.44$); 2, VR 27(24–28), box trainer 26(24–28) ($P = 0.77$); 3, VR 25(23–25), box trainer 29(26–29) ($P = 0.11$)].

Intraoperative Nissen Fundoplication

Statistically significant differences in time ($P < 0.001$), global rating scale score ($P < 0.001$), and checklist score ($P < 0.001$) were found between the 4 groups (VR trained, laparoscopic box trained, conventional residency, and laparoscopic expert) (Figs. 2, 3, and 4). The median time to complete the intraoperative suture in the VR group was 278 seconds (210–391), the box-trained group 263 seconds (240–311), the conventionally trained group 527 seconds (501–598), and the expert group 164 seconds (164–164). The OSATS score for the VR group was 24 (22–26), box-trained group 24 (23–25), the conventionally trained group 14 (13–16), and the expert group 29 (28–29). Finally the checklist score for the VR group was 23 (22–25), box-trained group 24 (23–24), conventionally trained group 12 (7–13), and expert group 27 (27–27). When comparing only the VR and laparoscopic box-trained groups, no significant differences were found for time ($P = 0.74$), global rating score ($P = 0.65$), or checklist score ($P = 0.97$). Residents who received only conventional residency training achieved the proficiency level equivalent to that of the VR and laparoscopic box-trained groups after 6 repetitions in the operating room (Friedman's Test, $P = 0.83$) (Fig. 5).

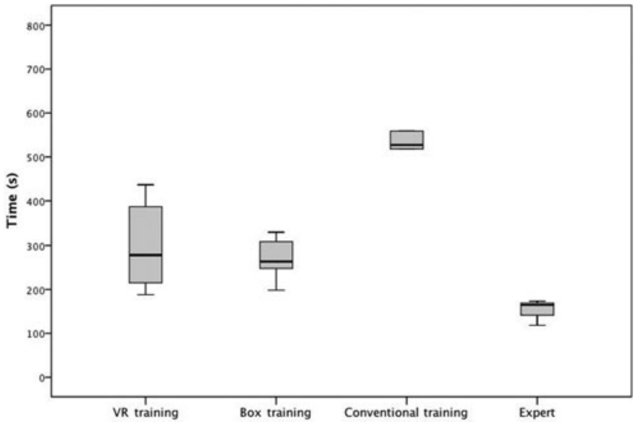

FIGURE 2. No significant time differences were found between the VR-trained group and the box-trained group as they performed an intracorporeal suture in the operating room. Both ex vivo trained groups, however, were significantly faster than conventionally trained residents. Horizontal bars, boxes, and whiskers represent the median, interquartile range, and range, respectively.

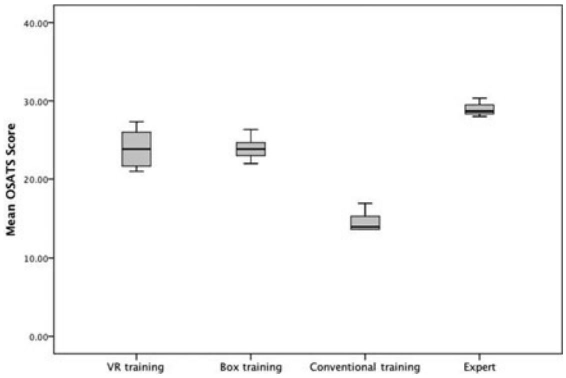

FIGURE 3. In the operating room, there was no statistically significant difference between the technical proficiency of the VR-trained group and the box-trained group as measured using a validated global rating scale (OSATS). Both ex vivo groups performed significantly better than conventionally trained residents. Horizontal bars, boxes, and whiskers represent the median, interquartile range, and range, respectively.

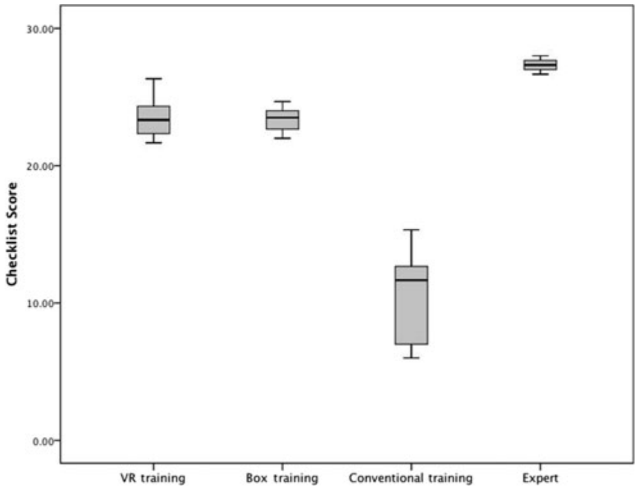

FIGURE 4. In the operating room, there was no statistically significant difference between the technical proficiency of the VR-trained group and the box-trained group as measured using a validated checklist assessment tool. Both ex vivo groups performed significantly better than conventionally trained residents. Horizontal bars, boxes, and whiskers represent the median, interquartile range, and range, respectively.

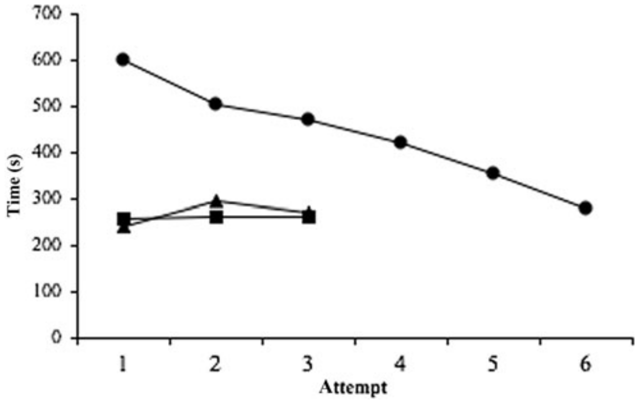

FIGURE 5. Residents who received only conventional residency training achieved the proficiency level equivalent to that of the VR and laparoscopic box-trained groups after 6 repetitions in the operating room. The circles represent the conventionally trained residents, the boxes the VR group, and the triangles the box-trained group.

Transfer-Effectiveness Ratio

Residents were trained on the VR simulator for a median of 17 minutes. In the operating room, it took VR-trained residents an average of 269 seconds for proficiency (the average of the median times for the 3 sutures in the operating room) (Fig. 5). It took conventionally trained residents 6 attempts in the OR to achieve the proficiency of the VR-trained group. The median times for the 6 suturing attempts were 598, 505, 469, 420, 355, and 280 seconds (Fig. 5). Applying these results to the TER equation: (2627 s – 269 s)/1020 s gives a TER of 2.31 for residents trained on the VR simulator. Conversely, residents trained on the box trainer for a median of 35 minutes. In the operating room, it took these residents on average 261 seconds for proficiency. Applying these results to the TER equation: (2627 s – 261 s)/2100 s gives a TER of 1.13 for the residents trained using the laparoscopic box trainer.

Cost Analysis

The annual cost of training 5 residents on the FLS trainer box is $11,975.00, on the VR simulator is $77,500.00, and on the conventional residency training is $17,380.00 (Table 1). These figures, however, do not take into account how these costs vary with the number of residents in a particular residency program, nor do they differentiate between initial costs, and ongoing costs of each training system. Over a 1-year period, FLS training is less costly than VR training for all Canadian residency general surgery programs, regardless of the number of residents. Over the same 1-year period, however, compared to conventional training, FLS training is only more cost-effective for programs with 6 or more residents (Table 2). Over a 5-year period, FLS training becomes the most cost-effective option for all Canadian residency programs, with VR training more cost-effective than conventional training only for larger programs with 10 or more residents (Table 3).

DISCUSSION

This randomized controlled trial described a proficiency-based VR and box-trainer curriculum to teach laparoscopic intracorporeal suturing. Both curricula conform to current educational standards of proficiency-based training, distributive practice, and summary feedback.[22–26] Although residents trained using both modalities demonstrated improved performance in the operating room compared to a group of conventionally trained residents, there was no significant difference between the technical performances of the 2 groups of ex vivo trained residents. It is perhaps not surprising that both VR training and laparoscopic box training resulted in similar technical performance both on a simulated model and in the operating room. Although both training methods are different, they each allow trainees to become familiar with the composite steps of the task, to become accustomed to the fulcrum effect of the instruments, and learn to follow the progress of a 3-dimensional task on a 2-dimensional screen. The fact that both groups of ex vivo trained residents performed superiorly to conventionally trained residents is in keeping with other studies demonstrating that basic technical skills learnt on VR simulators and box trainers transfer to the operating room.[15,27–30] This study, however, further quantifies the difference between conventional training and ex vivo training by demonstrating that it took conventionally trained residents 6 attempts to achieve the same proficiency in intracorporeal suturing as the 2 ex vivo trained groups. This represents a substantial saving in terms of operating room time and hospital costs and has significant implications for patient safety.

Another way of assessing the quality of a simulation device is by using the transfer-effectiveness ratio. This analysis originated in the airline industry and has been used in a limited fashion in the surgical educational literature.[20] This equation assesses the difference in time required to achieve performance criterion in an analogous clinical situation for simulation trained and untrained individuals. In this study, the transfer-effectiveness ratio for VR training was 2.31 versus 1.13 for box-trained residents. What this means is that every hour of training on the VR simulator represents 2.31 hours of conventional residency training, and that every hour of training on the laparoscopic box trainer represents 1.13 hours of conventional training. This data suggests that while both curricula prepare residents to be proficient with laparoscopic suturing before they reach the operating room, residents who were trained via the VR simulator are prepared in a more time-efficient manner. This could be due to the fact that residents in the VR training group practiced on the simulator at differing levels of difficulty starting at the easy level. The laparoscopic box trainer, however, is unable to be modified to become progressively more difficult. The importance of progressive training has been previously hypothesized in the literature[31] and perhaps allows a trainee to master a technical task in a more efficient manner.

TABLE 2. Cost of Laparoscopie Box Training, Virtual Reality Training and Conventional Residency Training Over a 1-Year Period in Residency Programs Across Canada

PROGRAM	Number of Residents	Laparoscopic Box Trainer	Virtual Reality Simulator	Conventional Training
Memorial University of Newfoundland	3	$8510.00	$77,500.00	$5214.00
Dalhousie University	7	$10,490.00	$77,500.00	$12,166.00
Université Laval	9	$11,480.00	$77,500.00	$15,624.00
Université de Sherbrooke	7	$10,490.00	$77,500.00	$12,166.00
Université de Montréal	10	$11,975.00	$77,500.00	$17,380.00
McGill University	7	$10,490.00	$77,500.00	$12,166.00
University of Ottawa	7	$10,490.00	$77,500.00	$12,166.00
Queen's University	3	$8510.00	$77,500.00	$5214.00
Northern Ontario School of Medicine	2	$8015.00	$77,500.00	$3476.00
University of Toronto	13	$13,360.00	$77,500.00	$22,594.00
McMaster University	8	$10,985.00	$77,500.00	$13,904.00
University of Western Ontario	6	$9995.00	$77,500.00	$10,428.00
University of Manitoba	5	$9500.00	$77,500.00	$8690.00
University of Saskatchewan	6	$9995.00	$77,500.00	$10,428.00
University of Alberta	8	$10,985.00	$77,500.00	$13,904.00
University of Calgary	6	$9995.00	$77,500.00	$10,428.00
University of British Columbia	8	$10,985.00	$77,500.00	$13,904.00

Highlighted cells represent programs where laparoscopic box training is less costly than conventional residency training.

TABLE 3. Cost of Laparoscopie Box Training, Virtual Reality Training and Conventional Residency Training Over a 5-Year Period in Residency Programs Across Canada

PROGRAM	Number of Residents	Laparoscopic Box Trainer	Virtual Reality Simulator	Conventional Training
Memorial University of Newfoundland	3	$18,840.00	$80,000.00	$26,070.00
Dalhousie University	7	$28,740.00	$80,000.00	$60,830.00
Université Laval	9	$33,690.00	$80,000.00	$78,210.00
Université de Sherbrooke	7	$28,740.00	$80,000.00	$60,830.00
Université de Montréal	10	$36,165.00	$80,000.00	$86,900.00
McGill University	7	$28,740.00	$80,000.00	$60,830.00
University of Ottawa	7	$28,740.00	$80,000.00	$60,830.00
Queen's University	3	$18,840.00	$80,000.00	$26,070.00
Northern Ontario School of Medicine	2	$16,365.00	$80,000.00	$17,380.00
University of Toronto	13	$43,590.00	$80,000.00	$112,970.00
McMaster University	8	$31,215.00	$80,000.00	$69,520.00
University of Western Ontario	6	$26,265.00	$80,000.00	$52,140.00
University of Manitoba	5	$23,790.00	$80,000.00	$43,450.00
University of Saskatchewan	6	$26,265.00	$80,000.00	$52,140.00
University of Alberta	8	$31,215.00	$80,000.00	$69,520.00
University of Calgary	6	$26,265.00	$80,000.00	$52,140.00
University of British Columbia	8	$31,215.00	$80,000.00	$69,520.00

Highlighted cells represent programs where laparoscopic box training, or VR training are less costly than conventional residency training.

The clinical significance of the TER is evidenced by our finding that conventionally trained residents required 6 practice attempts in the operating room to reach the technical proficiency level of the VR-trained cohort, who were trained on the simulator for only 17 minutes. Even if a certain proportion of the effect was not directly due to the VR curriculum itself, the VR exposure could still be saving substantial amounts of training time in the operating room. This is especially important in light of the fact that enabling trainees to access the VR simulator for 17 minutes of training is quite feasible. VR simulators do not require the need for an expert proctor, do not require the use of disposable equipment, and can be accessible to residents at any time of day.

The advantage of VR training was also demonstrated on the synthetic Nissen fundoplication model. Although the VR and box-trainer group had similar checklist and global rating scores on this model, VR-trained residents were more efficient and were able to complete the first knot significantly faster than box-trained residents. This is supported by several studies demonstrating the superior transferability of VR skills as compared to skills learnt in a box trainer to the execution of tasks in a simulated environment.[32–34] This can perhaps be explained by the fact that trainees at a more junior level experience considerable difficulty learning suturing in a virtual realty environment and report low levels of face validity for this particular task.[10,35,36] It can be hypothesized that learning on a more difficult model results in trainees requiring to focus more, and work harder, as they are learning the requisite task. As such, when required to replicate the skill in an easier environment (laparoscopic box trainer), they do so faster than residents who only practiced in the less complex environment. It should be noted, however, that other studies investigating the acquisition of basic minimally invasive technical skills report the equivalence of both VR and conventional box training.[37–39] Interestingly, the VR-trained group also required less time to reach proficiency than the box-trained group (17 minutes vs 35 minutes, $P < 0.001$) indicating that the increased speed of task execution did not occur at the expense of additional training time.

Although the 2 groups of ex vivo trained residents outperformed their conventionally trained peers, their performance in the operating room was significantly lower than fellowship-trained surgeons. This is not totally unexpected. Laparoscopic suturing is an advanced minimally invasive procedure, which is difficult to master. Training on simulated models is not designed to replace technical experience in the operating room. Rather, ex vivo training is designed to allow residents to surmount the early portion of the learning curve this allowing them to actively participate in a meaningful fashion in technical training in a real clinical situation.[31]

Although the results from this study imply that VR training may be more efficient than laparoscopic box training, it is important to underline that the costs associated with VR simulators are quite significant. On the basis of our cost analysis, over a 1-year period, the cost of VR training for 5 residents is $77,500.00, conventional residency training is $17,380.00, and laparoscopic box training is $11,975.00. Over a 5-year period, these associated costs change; with training on VR simulators being more cost-effective than conventional residency training only for large residency programs with more than 10 trainees. Ultimately, however, laparoscopic box training is consistently the less costly option, whether a 1 or a 5-year period is being assessed. This cost analysis clearly illustrates that the size of a residency program and the amount of funding available to a training program are factors that should be taken into consideration when deciding between a VR and laparoscopic box trainer for teaching laparoscopic suturing.

A potential limitation of this study is the fact that the conventionally trained residents were not included in the randomized controlled portion of the study and therefore did not receive a pretest. This was done deliberately because the pretest would provide additional training above what is conventionally provided during residency training. As such, performance of this group in the operating room was not contaminated with a potential training advantage. The corollary of this, however, is that it is impossible to definitively state that the control group residents were at a similar level of technical ability at the outset of the study compared to trainees randomized to the VR and box-trainer group.

This study demonstrates the validity of 2 proficiency-based training curricula to teach laparoscopic intracorporeal suturing. Training using either a VR simulator or a laparoscopic box trainer saves 6 practice-suturing attempts on a live patient in the operating room. Although the technical performance of both groups of residents was equivalent in the operating room, our results strongly suggest that VR simulation is the most time-efficient means for training residents in laparoscopic suturing, whereas box training is the more cost-effective modality. Because our data demonstrates that the final benefit from each training modality is equivalent, VR training may be a more appropriate option for larger programs with more funds, or with less available faculty facilitators. On the contrary, laparoscopic box trainers may be the preferred option in smaller programs, or where faculty are available to facilitate ex vivo teaching sessions.

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