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Augmented reality telementoring (ART) platform: a randomized controlled trial to assess the efficacy of a new surgical education technology

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Abstract

Background Laparoscopic skills training has evolved over recent years. However, conveying a mentor's directions using conventional methods, without realistic on-screen visual cues, can be difficult and confusing. To facilitate laparoscopic skill transference, an augmented reality telementoring (ART) platform was designed to overlay the instruments of a mentor onto the trainee's laparoscopic monitor. The aim of this study was to compare the effectiveness of this new teaching modality to traditional methods in novices performing an intracorporeal suturing task.

Methods Nineteen pre-medical and medical students were randomized into traditional mentoring ($n = 9$) and ART ($n = 10$) groups for a laparoscopic suturing and knot-tying task. Subjects received either traditional mentoring or ART for 1 h on the validated fundamentals of laparoscopic surgery intracorporeal suturing task. Tasks for suturing were recorded and scored for time and errors. Results were analyzed using means, standard deviation, power regression analysis, correlation coefficient, analysis of variance, and student's *t* test.

Results Using Wright's cumulative average model ($Y = aX^b$) the learning curve slope was significantly steeper, demonstrating faster skill acquisition, for the ART group ($b = -0.567$, $r^2 = 0.92$) than the control group ($b = -0.453$, $r^2 = 0.74$). At the end of 10 repetitions or 1 h of practice, the ART group was faster versus traditional (mean 167.4 vs. 242.4 s, $p = 0.014$). The ART group also had fewer fails (8) than the traditional group (13).

Conclusion The ART Platform may be a more effective training technique in teaching laparoscopic skills to novices compared to traditional methods. ART conferred a shorter learning curve, which was more pronounced in the first 4 trials. ART reduced the number of failed attempts and resulted in faster suture times by the end of the training session. ART may be a more effective training tool in laparoscopic surgical training for complex tasks than traditional methods.

Keywords Augmented reality · Telementoring · Telestrating · Laparoscopic · Training

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Laparoscopy requires the development of specialized psychomotor skills which are most effectively learned with hands-on practice and feedback [1, 2]. The fidelity of feedback is equally important to the quantity of hands-on practice [2]. This is the theory behind augmented reality simulators that provide haptic feedback along with the use of authentic surgical instruments, visual cues, and objective assessment [3, 4]. However, simulators are most effective when, in addition to the above features, a mentor is involved in training, specific goals are outlined, and complete surgical procedure simulations are used [1, 3–10].

Simulators have been shown to bring trainees' skills past the level of the learning curve for laparoscopic procedures [7, 11, 12], yet formal mentoring remains advantageous and supervised hands-on training is still required of surgical residency programs. Results of complex laparoscopic procedures have been shown to be equivalent between mentored trainees and expert surgeons, while allowing trainees to acquire new skills, improve technique, and gain confidence in minimally invasive surgery without additional risk to the patient [13]. Technological advances have allowed for the advent of telemedicine, and telementoring with telestrating has been shown to be as effective as on-site mentoring during the laparoscopic surgical skills training using a virtual reality simulator [6]. Additionally, telementoring has been shown to increase the quality and availability of laparoscopic surgery [6, 14–17]. Telementoring and telestrating may be beneficial for training surgeons in more advanced techniques and provide accessibility to remote locations or community hospitals, while decreasing travel costs for patients, mentees, and mentors [6, 14–16]. However, the expense of telemedicine systems, their installation, maintenance, and broadband services may outweigh this cost savings especially if patient volume is low [17].

Increased time restrictions on residents' working hours, increased patient load of attending surgeons, and increased operating room costs make it necessary to develop a more efficient hands-on training technique [1, 11]. While augmented reality simulators are suggested to be superior to and preferred over virtual reality simulators by expert surgeons and trainees [3, 4, 18], they also have been shown to improve surgical skills and may reduce the learning curve for laparoscopic training [19, 20]. Augmented reality has also been used in the operating room to provide three-dimensional image overlay of anatomical structures resulting in increased surgical precision in laparoscopy [21, 22]. However, with the obvious utility of augmented reality it has yet to be used in the operating room as a training aid.

The aim of this initial study was to demonstrate the effectiveness of ART in laparoscopic training of novices compared to the traditional method of verbal cues and physically pointing at the monitor in a complex laparoscopic task.

Methodology

This randomized controlled trial trained novices in intracorporeal suturing within the surgical simulation laboratory of an academic surgical program. Nineteen medical students (MS1 and MS2) participated and were randomized into traditional mentoring ($n = 9$) and ART ($n = 10$) groups. All nineteen subjects had no previous laparoscopic experience. Consent was obtained and the participants were randomly assigned and blinded to whether they were in the experimental or control group.

Sample size was determined by a statistical power calculator for t test with a Cohen's d of 0.8, probability of 0.05, and with a power of 0.8.

As all subjects were novices with no previous laparoscopic surgery exposure, they were oriented to the laparoscopic surgical platform by completing the validated fundamentals of laparoscopic surgery (FLS) Peg Transfer Task within 96 s, representing twice the expert proficiency, for two consecutive trials. Once this goal was attained, they were no longer allowed to practice. All subjects returned within 10 days of initial training to perform the experimental portion of the study. All subjects were oriented to the instruments and watched the FLS video in which the intracorporeal suturing task was explained and demonstrated. Requirements for the task included: placing a suture through two dots on a longitudinally slit Penrose drain, tying the knot tightly enough to close the slit, refraining from avulsing the drain off the block, finishing with three square throws, and cutting the suture.

Subjects were randomly assigned to one of the two groups. The control group ($n = 9$) was instructed verbally in-person by an expert with the ability of the trainer to point to the screen. The experimental group ($n = 10$) was taught by an expert using the augmented reality telementoring (ART) platform. Both groups were instructed by the trainer in a standardized step-by-step manner using only verbal cues derived from a predefined script. The subjects were required to complete each suture after their initial needle placement. Subjects and trainers were in continual visual and audio contact.

The time for each suture task was recorded (beginning when both instruments were seen on the screen and finishing when both sutures were cut). If critical errors were made, defined as cutting, tearing, or avulsing the drain, the task was recorded at maximal time limit (10 min) and the equivalent of 10 errors was assigned. Each millimeter the needle insertion was placed away from the dots was counted as one error. Air knots, insecure knots, and small tears were also counted as errors. Each error was given a 5 s time penalty which was added to the trial's suture time.

Each subject completed 10 suture attempts or as many attempts as could be completed within 1 h in order to avoid fatigue. All attempts were video recorded.

After the experimental group completed their training, they were asked to complete a questionnaire regarding their opinion on seven aspects of their experience using the ART platform.

Equipment

Figure 1 provides a digital image of the telementoring system used in this study for laparoscopic procedure training including a mentor environment (labeled Mobile Mentor) and a trainee environment (labeled OR (operating

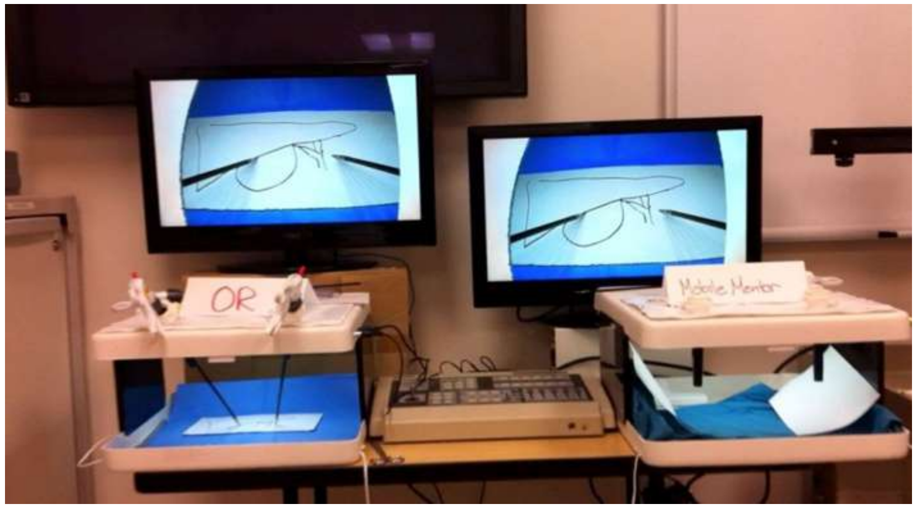

Fig. 1 A digital image of the ART platform

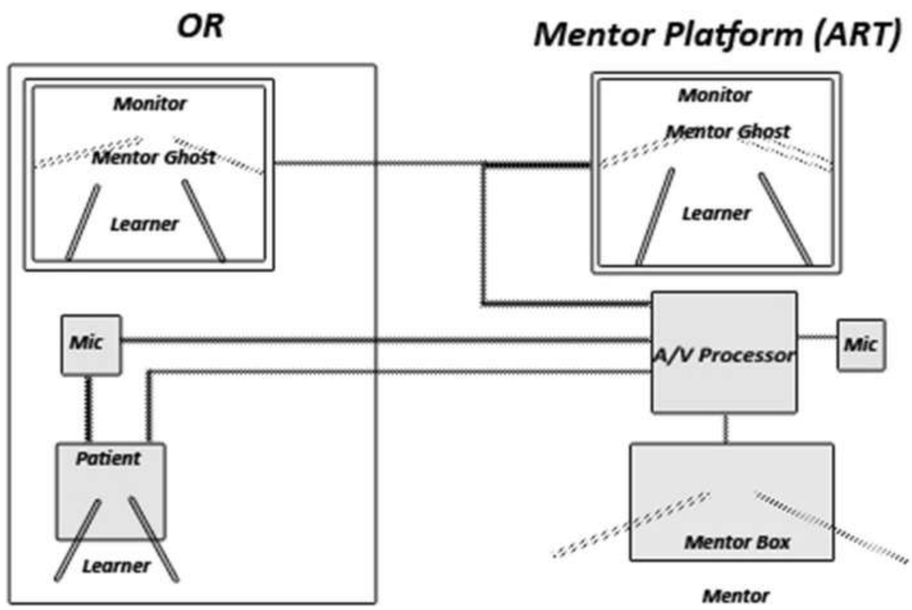

Fig. 2 A technical schematic drawing of the ART platform

room)). Figure 2 is a technical schematic drawing of the ART platform. In this particular example, the mentor environment includes an ART platform with a simulator, such as a portable laparoscopic training box simulator and an A/V processor/filter/mixer. The ART platform includes Chroma key technology and a camera so that the entire image captured by the portable laparoscopic training box simulator's camera has a green screen background. Laparoscopic instruments identical to those being used in the hypothetical operating room are introduced into the simulator box and during mentoring are operated as usual (e.g., as used by the surgeon if performing the task).

The training environment includes a trainee system with two laparoscopic trainee instruments and an image device which allows the trainee instruments and surrounding image field to be provided to the mentor environment. Additionally, a trainee microphone is coupled to the trainee system and a trainee display is coupled to the mentor environment to result in a telementoring system which allows an image of the mentor instructional laparoscopic instruments to be superimposed on the trainee's monitor allowing a mentor to provide real-time audio and visual guidance to a trainee during the laparoscopic procedure.

Results

Eighteen participants completed the trial. One subject did not complete the trial according to guidelines due to noncompliance. The time on first attempt for the peg transfer task was not statistically significant between the control and ART groups ($p = 0.7247$). Additionally, the number of

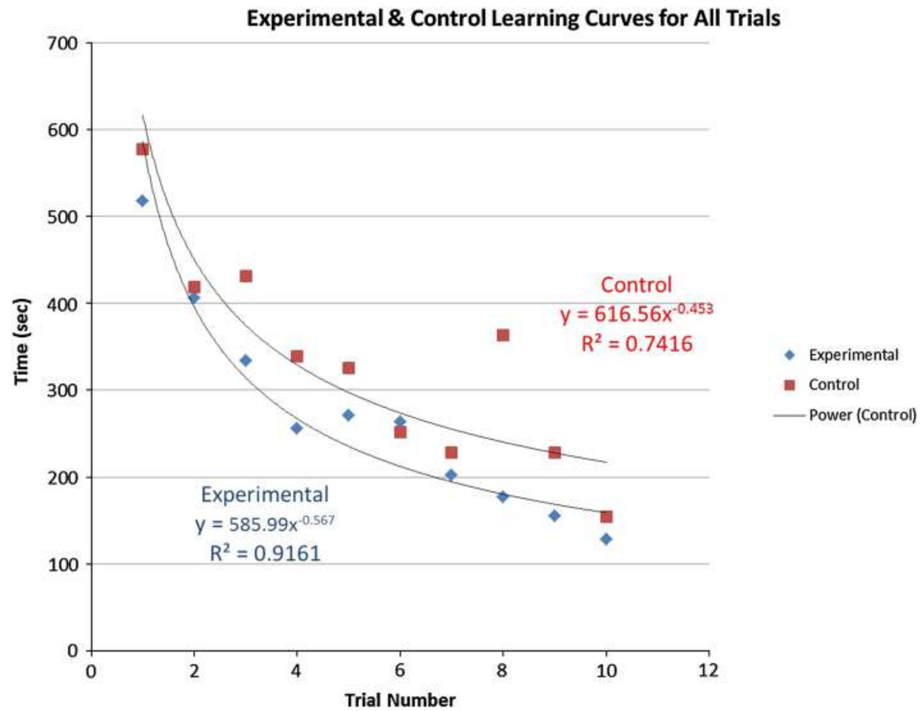

Fig. 3 Graph of experimental and control learning curves for all trials using Wright's cumulative average model ($Y = aX^b$) showing the control group's (*squares*) slower skill time acquisition versus the ART group (*diamonds*)

times required to obtain two consecutive tasks in 96 s or less was not statistically significant ($p = 0.1375$). This demonstrates that the control group and experimental group were equally inexperienced in the laparoscopic skills (Table 1).

Using Wright's cumulative average model ($Y = aX^b$) the learning curve slope (Fig. 3) was significantly steeper and shorter, demonstrating faster skill acquisition, for the ART group ($b = -0.567$, $r^2 = 0.92$) than the control group ($b = -0.453$, $r^2 = 0.74$).

This difference was greater during the first 4 trials (Fig. 4) with ART having faster skill acquisition versus traditional training ($b = -0.484$, $r^2 = 0.88$, $p = 0.00016$ vs. $b = -0.342$, $r^2 = 0.95$, $p = 0.000009$). At the end of 10 repetitions or 1 h of practice (Table 1), the ART group was faster versus traditional training (mean 167.4 vs. 242.4 s, $p = 0.014$). Additionally, the ART group had fewer total fails (8), defined as a critical error or max time, than the traditional group (12). Although the ART group had more errors per subject, this was not a statistically significant difference (Table 1). The ART group was faster and was thus able to complete more attempts before the full hour time limit was met (mean 8.89 vs. 7.67, $p = 0.0208$). When more attempts are made, there are more opportunities for errors accounting for a larger total number of errors in the ART group. Therefore, the number of errors per attempt was calculated and showed no statistically significant difference between groups. Additionally, the ART group had 57 % fewer critical errors per attempt. This suggests that the ART group was faster without compromising accuracy.

The surveys (Table 2) showed eight of the nine subjects (89 %) agreed or strongly agreed that "the ART Platform is an effective mentoring device."

Discussion

The standard of laparoscopic surgical education includes observing procedures, practicing on virtual or augmented reality trainers, and finally hands-on practice in the operating room with a mentor verbally guiding the trainee. The advent of telementoring has been able to expand the use of laparoscopic surgery [6, 14–16] which is often preferred to open surgery by patients and physicians because of the cosmetic results, decreased post-surgical pain, shorter hospital stay, and quicker return to normal bowel movements [23, 24]. However, there are still limitations with current telementoring devices. This is especially true in more advanced procedures and with more inexperienced surgeons. In routine practice, the use of augmented reality to overlay an expert's surgical instruments onto the trainee's augmented reality view may reduce the need for mentors to take over the instruments during surgery. This may allow for increased hands-on practice by trainees, decreased operating time, and decreased expenses. Additionally, while current telestrating techniques allow for a mentor to draw illustrations over the mentees surgical view

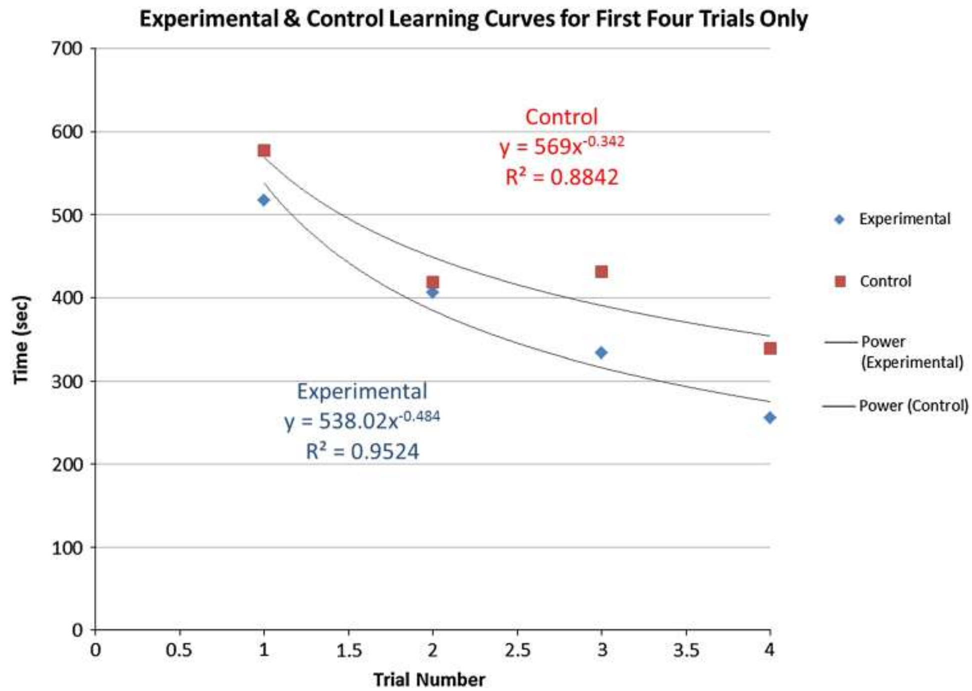

Fig. 4 Graph of experimental and control learning curves for first four trials only using Wright's cumulative average model ($Y = aX^b$) showing a more significant difference in skill time acquisition between the control group (*squares*) versus the ART group (*diamonds*)

Table 1 Parameter means[a]

	Control ($n = 9$)	ART ($n = 9$)	
Time on first attempt of Peg transfer	227.9 ± 211.9	192.2 ± 155.2	$p = 0.7247$
Attempts needed to complete Peg transfer	5.78 ± 1.1	4.89 ± 1.3	$p = 0.1375$
Initial suture time in seconds	577.3 ± 45.2	517.4 ± 128.9	$p = 0.1523$
Average suture time in seconds	362.6 ± 42.5	296.3 ± 90.4	$p = 0.0640$
Time at final throw in seconds	242.4 ± 59.0	167.4 ± 56.1	$p = 0.0138$
Number of attempts per subject	7.56 ± 1.2	8.89 ± 1.5	$p = 0.0424$
Number of errors per subject	17.67 ± 9.9	20 ± 7.4	$p = 0.5842$
Number of errors per attempt	2.23 ± 0.91	2.31 ± 0.90	$p = 0.8745$
Number of fails per subject	1.33 ± 0.87	0.89 ± 0.78	$p = 0.2699$
Total number of fails per group	12	8	
Number of critical errors per attempt	0.088	0.050	

[a] Data presented as mean ± standard deviation, or total number

Table 2 ART satisfaction survey[a] scored 1-strongly disagree through 5- strongly agree

Statement	Average response
1. I could reliably see the mentor's instruments	4.78 ± 0.44
2. I understand what the mentor's instruments were demonstrating	4.56 ± 0.53
3. My operative view was not obstructed	4.22 ± 0.67
4. The mentor assisted me effectively in completing the task	4.89 ± 0.33
5. I feel that my skill in the task has improved	4.89 ± 0.33
6. The ART platform is an effective mentoring device	4.44 ± 1.01
7. I would welcome ART mentoring in the OR	4.56 ± 0.73

[a] Data presented as mean ± standard deviation

[13], the use of actual instruments overlaid on the mentee's monitor will bypass the need for artistic skill on the mentor's part, and improve understanding and clarity of the desired positioning, and maneuvers. The ART platform allows the learner to be mentored remotely, both visually and audibly, using instruments identical to those being used by the learner. While the mentee performs the procedure, expert techniques are being demonstrated, in real-time, by the mentor. This both clearly and reliably guides the learner in a technically challenging arena. These aspects allow for real-time demonstration and lead-and-follow training, which produces high fidelity and immediate feedback to the trainee, resulting in a shorter and steeper learning curve as well as faster procedure times in a standardized task.

We propose that ART may prove to expand the use and efficiency of laparoscopic surgical training through a novel, intuitive method. This may also represent a safer, more effective training tool in telemedicine. A potential application of the ART platform would also be in the arena of robotic surgery where the mentor could act as a “flight instructor” with the ability to mentor by demonstration or easily take over the control of the instruments in necessary situations.

Conclusion

The ART platform may be a more effective training technique in teaching laparoscopic skills to novices compared to traditional methods. In this study, ART training produced faster skill acquisition in a validated intracorporeal suturing task. This difference was greatest in the first 4 trials. ART training reduced the number of failed attempts and resulted in faster task completion times by the end of the training session, without an increase in errors. ART may be a more effective training tool in laparoscopic surgical training for complex tasks than traditional methods. Further studies to assess the applicability of ART to remote locations and intra-operative mentoring during surgical procedures are underway.

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