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SURGICAL ENDOSCOPY
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Telementoring versus on-site mentoring in virtual reality-based surgical training

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Abstract
Background: Telementoring can be an adjunct to surgical training using virtual reality surgical simulation. Telementoring is hypothesized to be as effective as a local mentor for surgical skills training.
Methods: In this study, 20 Romanian medical students trained using a virtual reality surgical simulator (LapSim) with a telementor or local mentor. All the students watched an instructional module at the beginning of the exercise. The telementor, in the United States, interacted by videoconferencing. Before and after training sessions, tool path length and time for task completion were measured.
Results: Instructional media and training with mentoring resulted in similar levels of performance between locally mentored and telementored groups. Right- and left-hand path length and time decreased significantly within each group from the initial to the final evaluation ($p < 0.05$) for most tasks (grasping, cutting, suturing). No significant difference was achieved for clip-applying.
Conclusions: Integration of instructional media with telementoring can be as effective for the development of surgical skills as local mentoring.

Key words: Laparoscopic skills — Surgical training — Telementoring — Virtual reality

Training in surgery uses an apprenticeship model, in which residents assume more important roles in an operation as their experience increases [15]. This process is strictly supervised by surgeon educators, who watch the residents in the operating room and assess their abilities. In open surgery, the trainer surgeon always has control of the field, and through prompt physical intervention can easily prevent any harm an inexperienced trainee might initiate. Moreover, teaching can be performed while the attending surgeon uses the resident's instruments or guides the resident's hands in performing certain maneuvers. The same training protocol is not true for laparoscopy, in which the long instruments are not easily controlled from the opposite or trainer side of the operating table.

Many training programs use ways to prepare their residents in the laboratory with a skill level transferable to the operating room [12]. The two common teaching modes are (a) video and inanimate laparoscopic trainers and (b) computerized virtual reality surgical simulators. Inanimate laparoscopic trainers were first used, for several reasons. They are simple to build; they use real laparoscopic instruments; and basic laparoscopic tasks performed inside the trainer replicate basic tasks performed during an operation. Rosser et al. [10, 11] showed that analogous inanimate training could improve laparoscopic suturing.

Some investigators have attempted to develop computerized models of surgical techniques, with the purpose of both training and accurately evaluating trainees. Virtual reality laparoscopic simulators have been implemented in curriculums by different surgical programs for the training of their residents [3]. They reinforce motor skills through iterative performance. Most simulators currently available teach basic laparoscopy skills including grasping, cutting, clip-applying, and suturing. More advanced models have integrated modules for motion tracking [9, 14] and simulation of laparoscopic cholecystectomies, or use interfaces capable of providing tactile feedback [13, 14].

Although it is difficult to quantify surgical motor skills, virtual reality simulators are at least comparable with inanimate trainers and far more flexible [7]. Furthermore, some studies have shown that trainees with previous exposure to virtual reality surgical simulators

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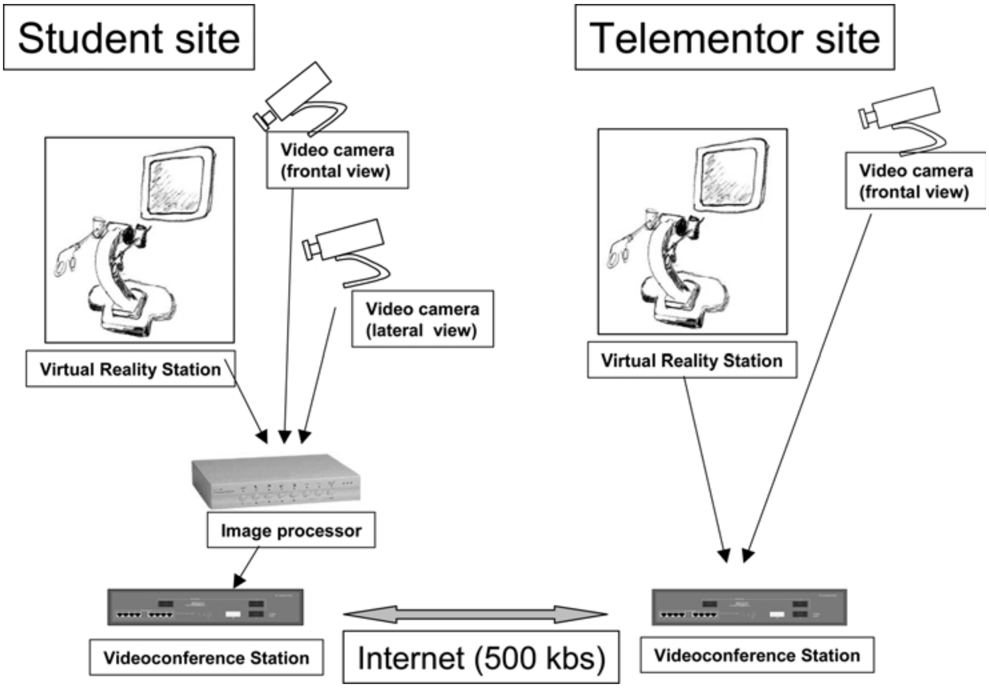

Fig. 1. Schematic of architecture for telementoring equipment setup in study. Illustrations by A. Rafiq.

do better in the operating room than nonexposed subjects [4, 5].

Although residents can always train individually with either inanimate trainers or virtual reality laparoscopy simulators, structured training with a mentor has been proven superior to unstructured solitary training [8]. The mentoring surgeon directly supervises the tasks and instructs the trainees in the correct way to accomplish them. Human factors and previous experience play an important role in this process. Therefore, the role of the mentor is difficult to dismiss. Integration of current technology for distance education provides a mechanism for content delivery to an audience located in a location different from that of the mentor. This study tested whether telecommunications could deliver the benefits of personal real-time mentoring for quantifiable structured skill acquisition of virtual reality simulation.

Materials and methods

The purpose of the study was to assess telementoring as an adjunct tool for surgical training using the LapSim surgical simulator (Surgical Science AB, Gothenburg, Sweden). The participants in the study were 20 medical students with no previous laparoscopy experience. They were tested in performing four laparoscopic skills: grasping, cutting, clip-applying, and suturing. Testing took place at the beginning and end of the study. Between these end points, the participants were divided into two groups, which trained, respectively, with a local mentor or a telementor. The telementor coach actively engaged the trainees by voice and telestrator to guide them in skill acquisition.

For the first task, grasping, the trainees had to use each hand alternatively to grasp six objects randomly spread in the simulated operative field. Upon grasping, the trainee had to place each object in a sphere and hold it steady until the sphere disappeared before being able to move to the next object.

In the cutting task, the students had to grasp and stretch, with the nondominant hand, the loose end of a simulated blood vessel, and subsequently use the dominant hand to cut a piece of this vessel. The same task was repeated three times, as the vessel shrank with every piece cut.

In clip-applying, the students had to grasp and stretch with one instrument the middle of a simulated blood vessel with both ends anchored to the surrounding tissues. The other instrument was used to apply clips on both sides of the grasped area. In certain circumstances, the vessel could rip if stretched too hard, and more complex actions were required to complete the task: both ends of the ripped vessel had to be grasped and clipped individually and the blood aspirated from the field. These maneuvers required increased eye–hand coordination for completion.

For the last task, suturing, the trainees had to pass a needle with the dominant hand through a specific area of a simulated tissue. Upon penetrating the tissue, the trainee had to grasp the needle with the nondominant hand and extract it from the tissue. If the movement was not smooth and the movement of the hand did not follow the curvature of the needle, the tissue would rip, and the task had to be restarted.

The 20 medical students were randomly divided into two groups of 10 each. A demonstration of the correct way to perform each task was provided to all participants at the beginning of the study, after which an initial evaluation of performance was carried out for all the students (E0). On a subsequent day, the students in the two groups were trained for 30 min each. The first group had a mentor on site (local) and could interact by voice and by sharing the same visual field during the training sessions. The second group had a remote mentor (telementor) located in a geographically distant location. Telementoring was conducted using videoconferencing. In this instance, mentor and students also shared a common visual field and had real-time audio interaction. An evaluation session was carried out at the completion of the mentoring session (E1), and the performance of the telementored group was compared with the performance of the group that had received local mentoring.

Two sites (Virginia Commonwealth University, Richmond, VA, and Fundeni Clinical Institute, Bucharest, Romania) integrated video output from the LapSim monitor into Polycom videoconferencing equipment (Fig. 1). The connection was realized via transmission control protocol/internet protocol (TCP/IP) at an average speed of 500 KB. A lateral view room camera showed the trainee in profile, allowing assessment of posture and movement ergonomics. An additional frontal view camera captured hand motion.

The video signals from the two room cameras and the LapSim monitor were integrated into an AVC704 Quad Processor (AV Tech Corporation, Taipei, Taiwan) and outputted as a single, composed image for the videoconferencing transmission. Thus, the telementor

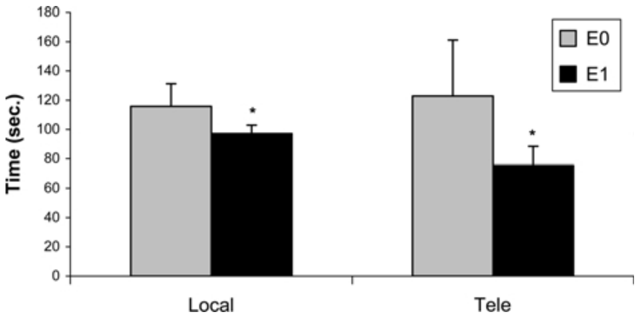

Fig. 2. Grasping task performance time (s) plotted relative to baseline activity (E0) versus postmentoring session (E1). Local (mentoring present locally). Telementoring (conducted remotely using telementoring setup). *$p < 0.05$.

was aware of the students' body or wrist posture while performing the tasks and could correct them as necessary. The use of a telestrator expanded capabilities by allowing overlay of line drawings by the mentor to the image seen by the trainee. The telementor also was able to demonstrate the correct performance during training using the LapSim interface. The on-site mentor also advised and interacted as indicated.

The end points of the study were right- and left-hand path lengths and total time required to perform each task. For the statistical analysis, we deleted one outlier from outside the 95% confidence interval. The average values of all parameters at the initial evaluation were compared against the final evaluation for each group individually. Statistical analysis was achieved by running the Student *t*-test using Sigma Plot (SSPT) software. We sought thus to measure the value of on-site mentoring versus telementoring in the students' performance.

Results

All 20 medical students who volunteered to participate in this study completed it. The volunteers were randomized to one of two groups relative to mentoring: local mentoring or telementoring. The data in this study suggest that telementoring with educators in geographically distant locations can be integrated into a medical educational system.

Task performance

The data plotted in Figs. 2 to 5 reflect the average number of seconds required to complete the assigned tasks before mentoring (gray bars) and after the training session (black bars). The number of seconds required to complete the tasks decreased after training. The clip-applying task was not especially challenging and did not improve with training. All the other tasks (grasping, cutting, suturing) were significantly faster after training.

Comparison of performance between the baseline (E0, gray bars) and posttraining sessions (E1, black bars) for each of the four tasks is discussed individually in the order of their presentation during the study. The telementored (tele) students performed just as well as those trained on site (local).

Grasping

In completing this task, both left- and right-hand movements were coordinated independently of each other for a successful grasp of the simulated vessels as they appeared on the screen. A total of six vessels had to be grasped to complete the session in the simulation. The data in Fig. 2 show that task performance time significantly decreased by 16% ($p < 0.05$) from baseline to postmentoring with the local mentor present (local). In contrast, the performance time decreased by 39% ($p < 0.05$) with the telementor present. The participants showed a statistically significant decrease in the time consumed to complete tasks after mentoring ($p < 0.05$).

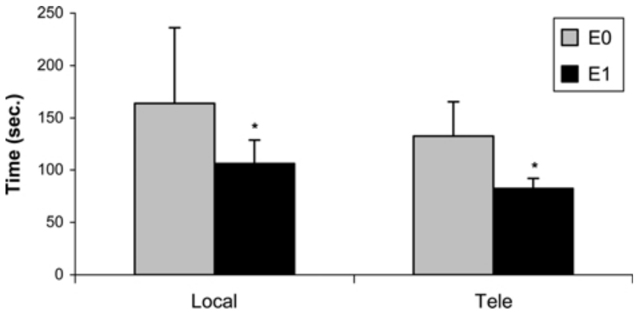

Fig. 3. Task performance time (s) for cutting plotted to indicate baseline activity (E0) versus postmentoring session (E1). Local (mentoring present locally). Tele mentoring (conducted remotely using telementoring setup). *$p < 0.05$.

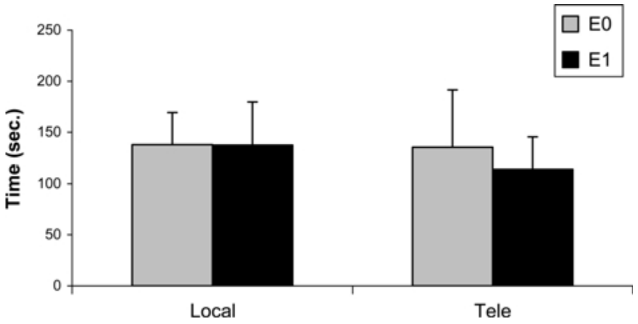

Fig. 4. Clip-applying performance time (s) plotted for a comparison of baseline activity (E0) with the postmentoring session (E1). Local (mentoring present locally). Telementoring (conducted remotely using telementoring setup).

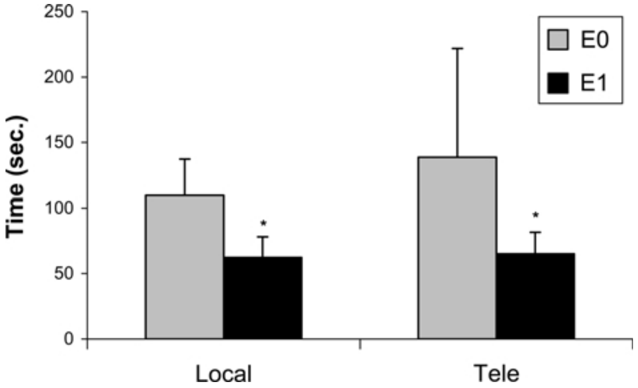

Fig. 5. Suturing task performance time (s) plotted for a comparison of baseline activity (E0) with the postmentoring session (E1). Local (mentoring present locally). Telementoring (conducted remotely using telementoring setup). *$p < 0.05$.

Cutting

Both left- and right-hand-coordinated movements were required to manage the simulated vessel in the attempt to perform this task. The maximum number of cuts possible in the simulated tissue interface was six. The trend in proficiency from baseline (E0) to postmentoring (E1) was a 35% decrease with a local mentor ($p < 0.05$) (Fig. 3). The effect of telementoring, on the other hand, resulted in a significant 38% decrease in time consumed to complete the maximum number of possible cuts ($p < 0.05$). The degree of variability in performance among performers in each group is statistically significant.

Clip-applying

In performing the clip-applying task, each performer was limited to applying a maximum of six clips. The data plot shows a less significant decrease in task performance efficiency relative to time consumption after mentoring (Fig. 2). With local mentoring, no significant decrease in time expended was noted for application of all the clips provided in the simulation to complete the task ($p < 0.05$). From the baseline session (E0), as compared with the test session (E1), there was a 16% decrease in the number of seconds used for task completions with telementoring present.

Suturing

The performance for the suturing task is plotted in Fig. 5 for the locally mentored and telementored groups. This task required the passing of the needle into the tissue interface in a premarked target zone. The time required to pass the surgical needle completely through the tissue surface was 110 s without mentoring and 62 s with mentoring. The data show that time efficiency for the suturing task performance improved by 43% after local mentoring of skills ($p < 0.05$). In the comparison of E0 (baseline) time consumption with that of E1 (postmentoring), it can be noted that the suturing task was completed with 53% less time consumption after telementoring ($p < 0.05$).

Economy of movement

The relationship between performance of the tasks and economy of movement is plotted in Figs. 6 to 9. In this study, the term ‘‘economy of movement’’ is defined as the total length traveled by each laparoscopic tool in achieving the skills assigned for completion of the selected task. From within the LapSim software tool, maneuverability measured by path length was quantified relative to the total movement of the dominant right hand and nondominant hand (left) during performance of the task.

Grasping

In the grasping task, the path length was dictated by each hand moving independently of the other to grasp the simulated vessels and place them in the target zone. The task was completed when a total of six vessels had been placed in the target zone. The data in Fig. 6 show that path length decreased from baseline to postmen-

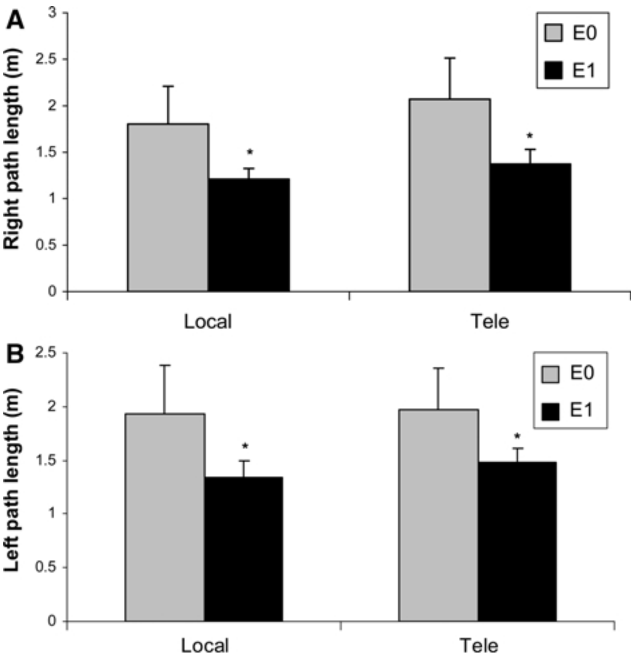

Fig. 6. **A** Path length (m) for right hand during grasping task performance plotted for a comparison of baseline activity (E0) with the postmentoring session (E1). **B** Left hand path length during grasping performance with baseline (E0) versus postmentoring (E1). Local (mentoring present locally). Telementoring (conducted remotely using telementoring setup). *$p < 0.05$.

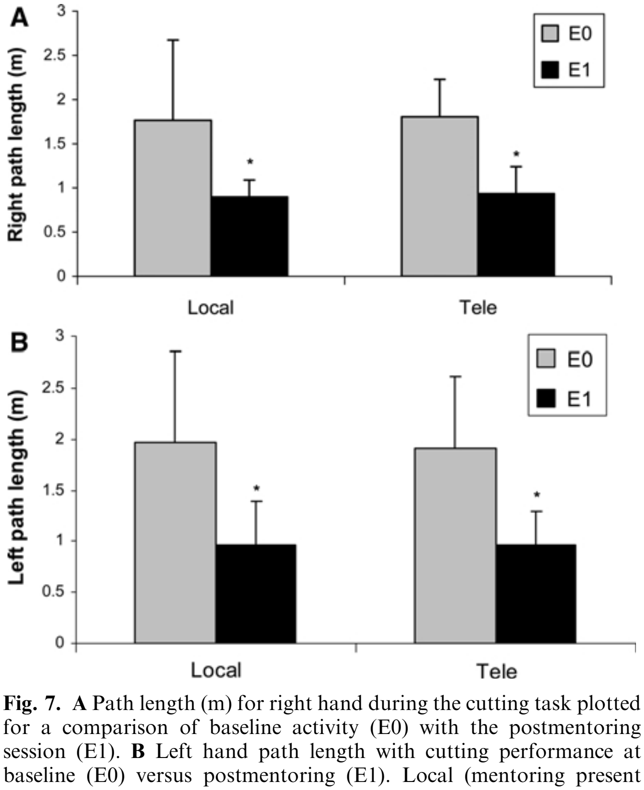

Fig. 7. **A** Path length (m) for right hand during the cutting task plotted for a comparison of baseline activity (E0) with the postmentoring session (E1). **B** Left hand path length with cutting performance at baseline (E0) versus postmentoring (E1). Local (mentoring present locally). Telementoring (conducted remotely using telementoring setup). *$p < 0.05$.

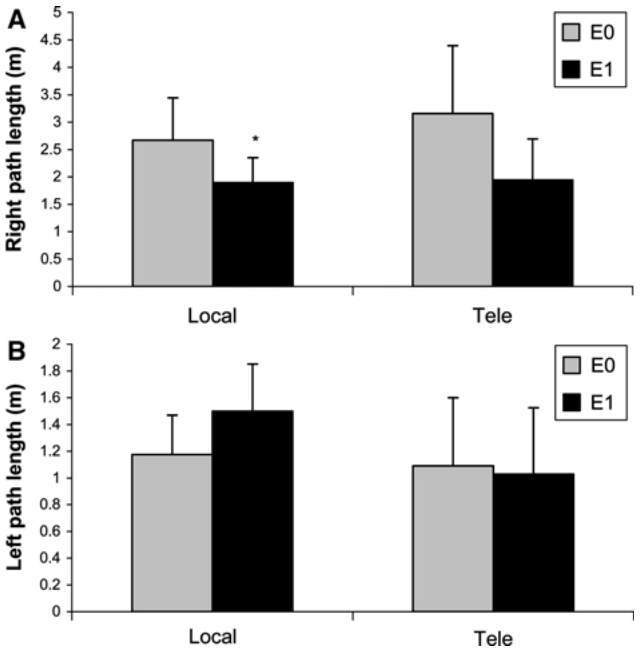

Fig. 8. **A** Path length (m) for right hand during clip-applying for a comparison of baseline activity (E0) with the postmentoring session (E1). **B** Left hand path length during clip-applying for a comparison of baseline (E0) with postmentoring (E1). Local (mentoring present locally). Telementoring (conducted remotely using telementoring setup). $*p < 0.05$.

toring for each hand with either the local mentor or the telementor present ($p < 0.05$).

Cutting

Both left- and right-hand-coordinated movements were required to manage this task. The path length generated by the left hand resulted from the attempt to grasp the simulated vessel end and then stretch it to expose the target zone for cutting. The right hand path length was generated by approaching the vessel, straddling it, and cutting the vessel. In each instance, the path length decreased after mentoring, indicating efficiency in skill performance ($p < 0.05$).

Clip-applying

In accomplishing the clip-applying task, path length was generated by moving the left hand to grasp the simulated vessel in the mid region, stretching the vessel, and using the right hand to apply the clips in target zones on either side. This task was less taxing in coordination because the left hand was easily maneuvered in depth to grasp the vessel and provide alignment for clip application by the right hand. The data plot shows an equal performance after each session before training and after mentoring. This data trend indicates that no new skills to perform this task were acquired after mentoring (Fig. 8). Statistical significance is noted with an asterisk when the *p* value is less than 0.05.

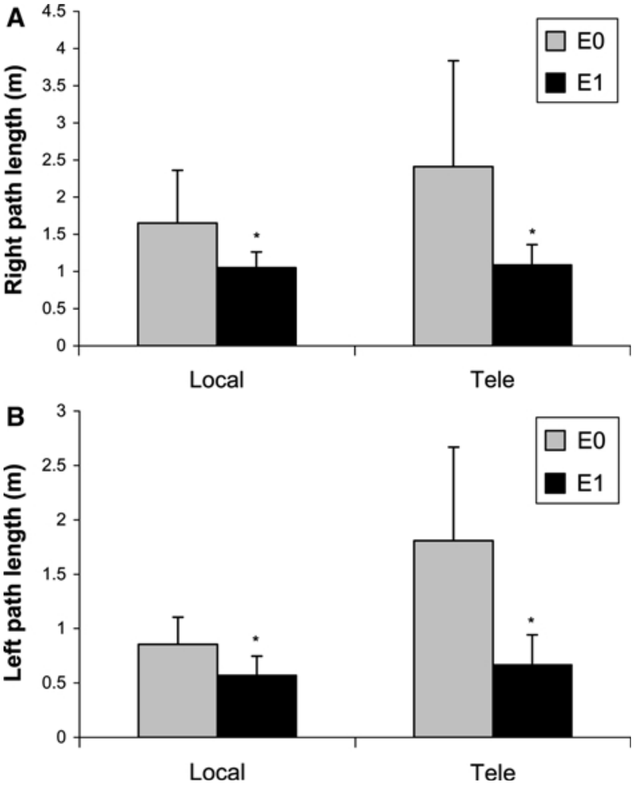

Fig. 9. **A** Path length (m) for right hand motions during suturing plotted for a comparison of baseline activity (E0) with the postmentoring session (E1). **B** Left hand path length during suturing with baseline (E0) versus postmentoring (E1). Local (mentoring present locally). Telementoring (conducted remotely using telementoring setup). $*p < 0.05$.

Suturing

The path length for performing the suturing task was significantly improved after both local mentoring and telementoring. The data plotted in Fig. 9 show that task performance was improved with the requirement that the needle be grasped initially with the left hand, aligned, and then passed to the right hand for insertion into the tissue interface in a premarked target zone. The data show that baseline path length (E0) was improved after the postmentoring session (E1).

Statistical significance was noted in each category with a *p* value less than 0.05. Overall, the participants performed with a greater degree of skill improvement and economy of movement after mentoring in task completions during the testing session.

Discussion

The data from this study show that the level of performance for each of the tasks, except clip-applying, improved when performed after mentoring. This improvement in performance validates the mechanism for application of distance education, with real-time interaction incorporating current videoconferencing technologies in conjunction with a virtual reality simulator for surgical skills. Virtual reality simulators as mechanisms for assessment of skill performance have been used in earlier studies with experienced surgeons [1]. These studies have noted that training with virtual reality simulators does improve performance in completing assigned tasks faster with lower error rates and greater economy of movement.

The benefit in using virtual reality simulators to evaluate skill performance capabilities is that there is less variability in the assigned tasks. The tasks and the associated environmental conditions are consistent for each participant. Thus, variables such as tissue characteristics or the influence of patient characteristics do not come into play in the virtual reality setup, allowing for repeat performance and assessment under all conditions.

The assigned task performance in this study posed the limitation of interpreting visual cues from a two-dimensional video interface in order to maneuver simulated laparoscopic tools in a three-dimensional simulation environment. An additional limitation in this study was the lack of physical feedback on the laparoscopic tool handles. The consequence was that all performance was achieved with only visual stimuli and no sense of force application at the tool–tissue interface. However, studies have noted that simulation training can be translated effectively into surgical skills in the operating environment [2]. Assessment of surgical skills transfer from the virtual reality environment to the performance of laparoscopic cholecystectomy on human patients indicated a 29% increase in the rate of performance [12].

With laparoscopic techniques merging into the mainstream of surgical procedures, there is no standard effective assessment tool to use during training in laparoscopic tool application. With the current study, the skill-oriented educational activity integrated the use of both virtual reality software and standard mentor lead guidance. The basis for effective education is outlined by the Institute of Higher Education in response to surveys of faculty and administrators evaluating benchmarks essential for quality distance education [6]. To be most successful, numerous benchmarks are recommended by the Institute for Higher Education Policy, including sound technology, standards for course development and delivery, periodic update of content, student faculty interaction, and evaluation and assessment of the program using standards.

The current study incorporated the suggested benchmarks by integrating simulation technology and real-time faculty interaction. Additionally, the mechanism of instruction presented in this discussion allows for repeat performance in a controlled environment without restriction on accessibility of resources and time constraints. The data reported in the current study indicate that it is possible to train medical students to perform basic surgical skills effectively. In conclusion, implementation of simulation interfaces is a viable mechanism for training in surgical task performance.

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