Tele-Mentoring Using Augmented Reality: A Feasibility Study to Assess Teaching of Laparoscopic Suturing Skills

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***Abstract*—The work assesses the efficacy of computer based remote tele-mentoring system (i.e. when the mentor and mentee are physically separated) for teaching minimally invasive surgical skills. The visual cues used for tele-mentoring comprises real-time virtual surgical instruments' motion augmented onto the operative field and remotely controlled by the mentor. In the feasibility study, the surgical task of laparoscopic intracorporeal suturing was simulated among 18 mentor-mentee pairs. Three modes of mentoring were used. Mode-I included traditional learning using pre-recorded videos (in absence of a mentor). Mode-II used traditional in-person hands-on mentoring. In Mode-III, a tele-mentoring prototype was used that connected a mentee with a remote mentor. Error count and duration were recorded for a learning stage followed by a testing stage for the three modes. The results show the error count for Mode-III reduces significantly as compared to Mode-I in the learning stage. Similarly, the error count for Mode-III also reduces significantly as compared to Mode-I in the testing stage. The errors count for Mode-III were equivalent to that of Mode-II for both learning and teaching stages. Furthermore, in Mode-III the duration reduces from learning to testing stage exhibiting the learning effect. Thus, computer based remote tele-mentoring is effective and more convenient to demonstrate surgical sub-steps consisting of tool-tissue interaction facilitating surgical skill transfer.**

***Index Terms*—Telemedicine Systems, Tele-mentoring, Surgical Education, Surgical skills, Surgical Training**

I. Introduction

Surgical training has traditionally followed the apprenticeship model of "see one, do one, teach one" in order to master the basic psychomotor and cognitive competencies needed to perform surgical procedures safely [1]. Over time, this paradigm has evolved to include supervised pyramidal and rectangular residency models, originally pioneered by William Halsted [2] and Edward Churchill respectively [3]. These historic training approaches are time-bound, and lean heavily on the trainee's competitiveness, diligence, self-accountability, and endurance to master basic surgical competencies in the physical presence of the mentor. The transition to minimally invasive surgery (MIS) has added additional challenges to the traditional training process. In addition to basic surgical competencies, training for MIS necessitates mastery of visual tactility, economy of movement, dexterity, hand-eye coordination, and tissue handling while using a limited range of instrument motion. Furthermore, surgical training has recently received an enormous setback owing to the Covid-19 global pandemic due to exposure-minimizing protocols, reduction in surgical volume and subsequent training experience, and redeployment of experienced staff to non-surgical operations [4]. This has coincided with an already-strained healthcare system reeling with increasing deficiency of trained surgeons [5]. These factors have fueled the rise of tele-mentoring as a viable alternative to traditional in-person surgical training and supervision.

Currently, augmented reality-based immersive technologies exist to facilitate tele-mentoring for surgeons during MIS, using screen annotations [6], [7] or hand gestures [8], [9]. Several studies have also reported the effective use of augmented tooltip motions for surgical guidance in laparoscopic [10], [11] as well as robotic settings [11], [12]. However, these studies were conducted on a standalone system with the mentor and the mentee being in the same room rendering it unusable as a remote training modality. Enabling immersive and synchronous remote tele-mentoring could address the deficiency

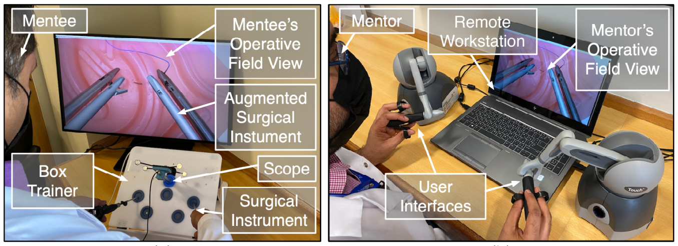


Fig. 1. Setup of the remote tele-mentoring prototype used in Mode-III. (a) Training site. (b) Remote site.

of on-site expert mentors in resource-deficient areas and enable measurable mentee-centric surgical skill acquisition across geographical boundaries. It can also facilitate an ideal learning environment through dynamic intellectualization, cognition, and association of required skillsets without the constraints of time or patient-safety [13]. By extension, it would also address the shortage of trained surgeons globally, as well as the lack of health equity.

Working towards this trend, this work aims to build on the efforts of the aforementioned studies and investigate the efficacy of remote tele-mentoring (i.e. when the mentor and the mentee are physically separated) for a standard surgical task. A remote tele-mentoring prototype was implemented to simulate a mentoring session for the surgical task of laparoscopic intracorporeal suturing. The user study conducted in this work among mentor-mentee pairs presents the comparison among (a) the traditional learning by pre-recorded audio-videos, (b) traditional in-person hands-on mentoring, and (c) remote tele-mentoring.

II. Materials and Methods

A surgical task of laparoscopic intracorporeal suturing was selected to simulate mentoring sessions. The task involves tying a knot within a cavity using laparoscopic instruments. A soft tissue suture pad (3D-Med Inc., USA) was used as a cavity and needle drivers (Richard Wolf Inc., Germany) were selected as laparoscopic instruments. Hold-needle technique was used for a suture size of 15 cm. The task was divided into ten steps and for each step, an error count was assigned (shown in the supporting video). The errors were assigned (based on scoring mechanism used in the previous suturing studies [14], [15]) to ensure: (a) minimal damage to the suture pad replicating tissue, (b) no unnecessary movement of the laparoscopic instruments, (c) correct placement of the knot with appropriate tension, and (d) fluid movement of the instruments. A needle was preloaded orthogonally to the surgical instrument (held in the dominant hand). The duration of the task was recorded when the needle penetrates the soft tissue suture pad till a square knot is executed.

The study was conducted under three modes of mentoring. In Mode-I, the mentee learned the steps by viewing the video of the surgical task without the presence of a mentor. In Mode-II, a mentor was present at the training site and demonstrated the surgical task to the mentee by either (a) taking control of the surgical instruments to show the required motion, and/or (b) explaining the required motion of the surgical instruments via hand gestures or physically pointing to the visualization screen displaying the operating field. In Mode-III, a remote tele-mentoring prototype (Fig. 1) was used [11], [16]. The prototype connected the mentee (at the training site) with the mentor (at a site geographically apart). Real-time view of the operative field acquired at the training site from the scope was shared with the mentor remotely over the internet (shown in Fig. 1). Virtual models of surgical instruments were augmented onto the operating field and rendered on the visualization screen of both mentor and mentee. The motion of the augmented surgical instruments was controlled remotely by the mentor using user interfaces [17]. This enabled the mentor to demonstrate to the mentee the required motion of surgical instruments. In addition, exchange of audio cues facilitated real-time interaction between the mentor and the mentee.

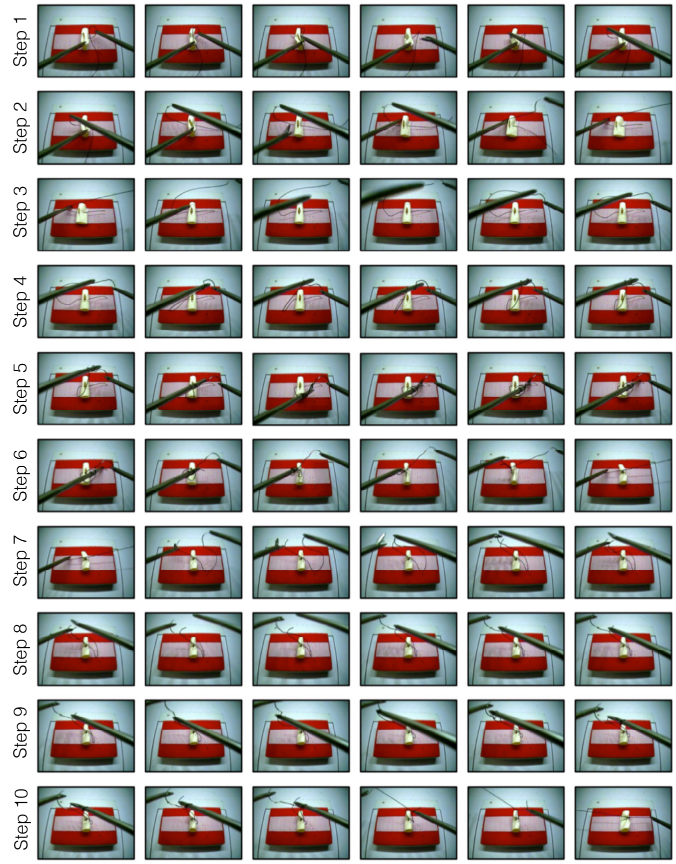


Fig. 2. Snapshots of the steps showing laparoscopic intracorporeal suturing task. The snaps are taken from St. John Surgical Residency FLS Expanded Video Tutorial Series: Task 5 - Intracorporeal Suture (Link: https://www.youtube.com/watch?v=hAzhqYid5jc).

The study involved 12 subjects as mentees with no prior knowledge of laparoscopic skills. The subjects were selected from the surgical department at Hamad General Hospital, Qatar. The user study was approved by the institutional review board comprising of the ethical committee (Medical Research Center, Doha, Qatar, approval number MRC-01-20-087). The mentees were randomly divided into two groups of six members and each group was assigned to Mode-II and Mode-III of mentoring. After a duration of two month, another group

TABLE I
STEPS TO COMPLETE LAPAROSCOPIC INTRACORPOREAL SUTURING TASK

Steps		Tool interaction in each step	Counted errors
Throw a stitch	Step 1	Hold the soft tissue suture pad using non-dominant hand and place the needle through the cavity using dominant hand	- Incomplete bite of the soft tissue suture pad - Trajectory does not follow needle curvature - Soft tissue suture pad is torn - Non-dominant hand holds the tissue aggressively - Needle doesn't remain in camera frame
	Step 2	Once the needle is placed through the cavity, use the non-dominant hand to protect the soft tissue suture pad while pulling the suture thread using dominant hand	- Needle is initially not pulled laterally - The needle is pulled away from the soft tissue suture pad without support from the tool - Thread tail is not left too short or too long - Needle does not remain in camera frame - Needle is pulled aggressively
Put the first throw of square knot	Step 3	Orient the needle in crescent shape such that suture thread and non-dominant hand tool are parallel	- Did not rotate the needle to downward crescent shape - The suture thread is not parallel to hub - The tool is not placed on top of the suture thread
	Step 4	Use the needle (held in dominant hand) to wrap twice around the non-dominant hand	- Did not rotate the needle to downward crescent shape - The suture thread is not parallel to hub - The tool is not placed on top of the suture thread
	Step 5	Grab the free end of the suture thread using non-dominant hand	- End of thread is not held
	Step 6	Pull the hand opposite to each other to put the first throw of the square knot on the soft tissue suture pad	- Non-dominant hand is not pulled first - Pulling is done upwards instead of sideways
Put the second throw of square knot	Step 7	Switch the needle from dominant to non-dominant hand such that suture thread and dominant hand tool are parallel	- Needle is not switched between hands - Did not rotate the needle to downward crescent shape - The suture thread is not parallel to hub - The tool is not placed on top of the suture thread
	Step 8	Use the needle (held in non-dominant hand) to wrap once around the dominant hand	- Wrapping and tying is done away from the soft tissue suture pad
	Step 9	Grab the free end of the suture thread using the dominant hand	- End of thread is not held
	Step 10	Pull the hand opposite to each other to put the second throw of the square knot on the soft tissue suture pad	- Non-dominant hand is not pulled first - Pulling is done upwards instead of sideways

of six members was created to represent mentees in Mode-I. Before the study, the mentor (with experience in teaching laparoscopic intracorporeal suturing) was first familiarized with user-interface of the tele-mentoring prototype. To remove any bias, a reference script was provided to the mentor. The script detailed the mentoring advice for the mentee to successfully execute the ten steps of laparoscopic intracorporeal suturing. The mentees were first introduced to laparoscopic setup used in the study and were briefed on the three mentoring modes. A pre-experiment peg transfer task (from Fundamentals of Laparoscopic Surgery [18]) was executed by each mentee to learn the hand-eye coordination required for laparoscopy.

The user study was conducted in the two stages: Stage 1 (learning stage) and Stage 2 (testing stage). In Stage 1, each mentee performed all the steps of the surgical task by observing the video in Mode-I and under constant guidance from the mentor in Mode-II and Mode-III. In Stage 2, the mentee performed the same surgical task but without any guidance. During the task, if the mentee was stuck and unable to proceed, assistance was provided. In case of Mode-I, the mentee was allowed to re-watch the video, whereas in case of Mode-II and Mode-III, mentor intervened and assisted the mentee. In both the stages, parameters (based on previous studies [19]–[21]) were recorded using an off-the-shelf video camera to assess the mentoring session. This included (a) cumulative error counts for all the steps, (b) duration it takes to complete each step during the mentoring session, and (c) the total duration to complete all the steps. These contributed to the response variables of the study. To examine the significance for the explanatory variables (i.e. Stage and Mode) of the study, a two-way with interaction ANOVA was performed for each response variable. If significant, a post-hoc analysis was followed using two-sample t-test to compare specific pairs. In both cases, all the model assumptions (i.e. normality and homoscedasticity) were tested and no violation was inferred.

III. RESULTS

The data of the user study for both the stages (Stage 1 and Stage 2) performed under the three modes of mentoring (Mode-I, Mode-II and Mode-III) are presented in Fig. 3. The cumulative error count for all the steps are shown in Fig. 3(a) and the ANOVA indicated that Mode was statistically significant ($p < 0.001$). The error count under Mode-I (9.00 ± 4.47) was higher as compared to Mode-II (3.33 ± 3.01, $p = 0.028$) and Mode-III (2.67 ± 2.25, $p = 0.011$) for Stage 1. This was also reflected for Stage 2, where the error count

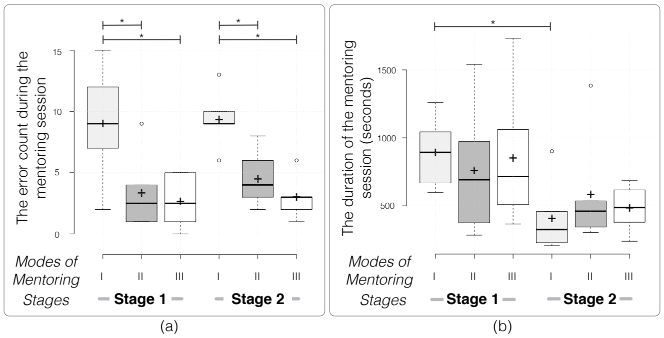


Fig. 3. (a) Error count during the mentoring session in Stage 1 and Stage 2 for each modes of mentoring. (b) Duration of the mentoring session in Stage 1 and Stage 2 for each modes of mentoring. '*' denotes p < 0.05

under Mode-I (9.33 ± 2.25) was higher as compared to Mode-II (4.5 ± 2.17, $p = 0.004$) and Mode-III (3 ± 1.67, $p < 0.001$). This shows in presence of assistance from a mentor (Mode-II and Mode-III), the mentees were able to learn and perform better as compared to learning from a video tutorial (Mode-I). Furthermore, no statistically significant difference was observed between the error counts under Mode-II and Mode-III for both the stages. Thus, both Mode-II and Mode-III were equivalent in teaching the mentees the techniques required for surgical task of laparoscopic intracorporeal suturing.

The total duration for the mentoring session is presented in Fig. 3(b) and the ANOVA indicated that Stage was statistically significant ($p = 0.008$). For all the modes, the average duration reduces: from 893 ± 259 seconds to 408 ± 258 seconds under Mode-I ($p = 0.009$), from 759 ± 456 seconds to 582 ± 405 seconds under Mode-II ($p = 0.492$), and from 850 ± 496 seconds to 482 ± 169 seconds under Mode-III ($p = 0.117$) for Stage 1 and Stage 2, respectively. In Stage 2, the mentees applied the learnings from Stage1. Thus, the mentor's involvements (in case of Mode-II and Mode-III) or the need to re-watch the mentoring video (in case of Mode-I) was reduced and resulted in decrease in the duration for Stage 2. No statistically significant difference was observed among the modes for the duration within either Stage 1 or Stage 2. I.e., it took an equivalent amount of time among all the modes to teach in Stage 1 and to demonstrate the learnings in Stage 2.

In addition, the exchange of information between mentor-mentee pair for each step was analyzed. Mode-I was excluded as no mentor was present during the mentoring session. The duration it takes to complete each step for Mode-II and Mode-III was recorded (Fig. 4). The preferred mode for each step (Fig. 5) based on ease of communication and duration between mentor and mentee is summarized in Table II.

IV. Discussion

The user study (using the paradigm of laparoscopic suturing) demonstrates the feasibility of imparting laparoscopic surgical skills remotely by a mentor to a mentee. The tele-mentoring platform (demonstrated in Mode-III) uses realistic dynamic visual cues generated by the mentor in real-time. This facilitates effective communication between the mentor and

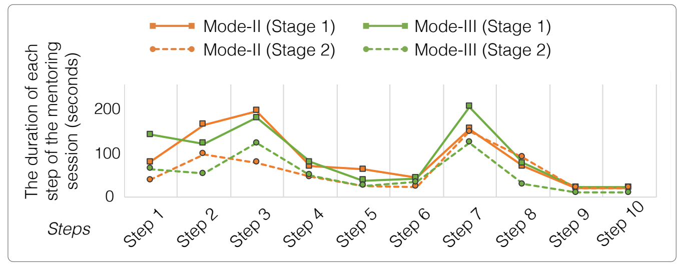


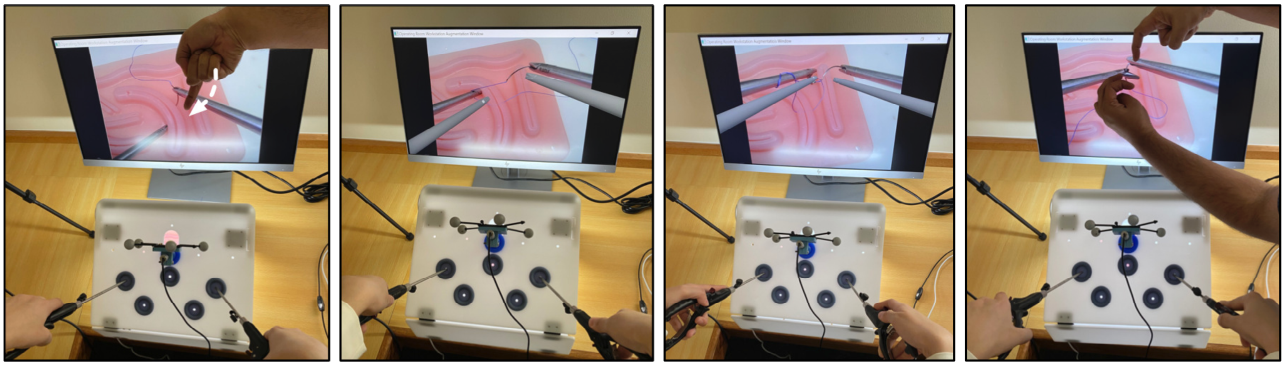
Fig. 4. Comparison of duration for each step of the mentoring session in Stage 1 and Stage 2 under Mode-II and Mode-III.

the mentee. As a result, the measured performance in terms of errors for the mentoring session using the tele-mentoring platform (in Mode-III) was: (a) better as compared to a pre-recorded video-based learning in absence of mentor (in Mode-I), (b) equivalent to that of traditional in-person hands-on mentoring (in Mode-II).

The mentoring performed under Mode-III offered several advantages. Instead of pre-recorded videos used in Mode-I, the tool-tissue interactions were displayed in the context of the operative field and thus removed any ambiguity. Secondly, as compared to Mode-II, mentee was in control of the surgical instrument throughout the mentoring session. Unlike Mode-III, in Mode-II if the mentee was not able to understand the steps of the surgical task from verbal instructions or hand gestures, the mentor took control of the surgical instruments to demonstrate the step. Thus, in Mode-III (as compared to Mode-II), there were no interruptions during the mentoring session related to switching of the surgical instruments from the mentor to the mentee.

Existing remote tele-mentoring platforms necessitates same laparoscopic setups for the mentee and the mentor at both training and remote site [10], [22]. The mentoring performed under Mode-III removes this dependency and facilitates usage of 'surgical procedure specific' or 'surgical skill specific' setups that need to be present only at the training site. The mentor using a remote workstation is able to connect to the training site and effectively explain the instructions required to execute each of the sub-steps. On the other end, the mentee is able to follow mentor's instructions and learn intrinsic details specific to the surgical procedure or skill.

Limitations specific to mentoring under Mode-III were also observed during the study. First, the mentor used ambiguous verbal instructions during Stage 1. For example, the mentor often used the words "this" or "that" to identify augmented surgical instruments and expected the mentees to understand. This underlines the need of a more structured surgical tele-mentoring curriculum with standardized lexicon and protocols [23]–[25]. Second, continuous rendering of augmented instruments obstructed the view of the operative field. This was evident when the mentor forgets to remove the augmented instruments from the view of the operating field after demonstrating the surgical step. In such a scenario, addition of an automated transparency features for augmented instruments (when mentoring is not needed) may be beneficial.



(a) (b) (c) (d)

Fig. 5. Mentoring performed at training site under (a) Mode-II for Step 1, (b) Mode-III for Step 2, (c) Mode-III for Step 5, and (d) Mode-II for Step 7

The study has several limitations. The study assessed the feasibility of using dynamic visual cues generated in form of augmented surgical instruments' motion for tele-mentoring and showed the visual cues assist mentor to remotely teach the task of laparoscopic suturing. However, further studies with additional subjects and increased sample size would be required to confirm if the remote tele-mentoring can be extended to teaching other surgical skills and the role it could play in surgical skill acquisition. Another limitation is, the study was not designed based on achieving proficiency goals for surgical training [26]. The aim of the study was not to achieve competency but rather to evaluate whether the information is effectively exchanged between the mentor and the mentee to facilitate surgical tele-mentoring. This is the reason only two stages (one as learning and other as testing) were used instead of performing multiple attempts till proficiency is reached. Thus, additional studies would be required to measure the learning curve for skill acquisition using the tele-mentoring platform. It would require conducting scenario-specific end-user studies to assess the efficacy of the mentee in understanding the information provided by the mentor via user interfaces [27]–[29]. Lastly, augmented hand-gestures of the mentor overlaid onto the operative filed has also emerged as an upcoming remote tele-mentoring tool (example includes iSurgeon [30] and Proximie [31]). As a part of future studies, we plan to compare the advantages of using augmented surgical instruments versus augmented hand-gestures. While the study was performed taking into consideration the clinical paradigm of laparoscopic surgery, the notion of using AR environment could be extended for open surgery using head mounted devices to augment the view of the mentee [32], [33]. Apart from the tool motion generated by the mentor, preoperative image data can be fused [34] to the operative field in AR environment to generate guidance contours [35]–[37].

V. Conclusion

In conclusion, the study findings are expected to have a positive impact on surgical training by contemporizing the age-old "see one, do one, teach one" model. The mentor is able to provide perspicuous instructions to the mentee in real-time using the augmented surgical instruments. The mentee is also able to thoroughly recall these instructions as they are shown in form of visual cues in the vicinity of the operative field. This facilitates remote transfer of surgical skills and have the potential to aid tele-simulation programs leading to a well-rounded surgical training curriculum.

TABLE II

Preferred Mentoring Mode for Steps of the Surgical Task

Surgical Task Step	Preferred Mode	Exchange of information between mentor and mentee
Step 1	Mode-II	In Mode-II, the scoop motion required to insert the needle through the slit on the tissue suture pad in step-1 was easy for the mentor to demonstrate to the mentee using wrist movements of the hand (Fig. 5(a)).
Step 2	Mode-III	The mentor was able to demonstrate the exact placement of the non-dominant tool to hold the tissue and motion required to pull the needle away from the tissue, using the augmented surgical instruments (Fig. 5(b)). Whereas in mode-II, it was difficult for the mentee to understand the verbal instructions and convert it into actions.
Step 5	Mode-III	In Mode-III, the mentor was able to demonstrate using augmented surgical instruments the movements required to grab the free end of the suture thread (Fig. 5(c)).
Step 7	Mode-II	In Mode-II, while switching the needle from dominant to non-dominant hand, mentor was able to demonstrate easily using hand gestures the required pose of the needle (Fig. 5(d)).

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