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ORIGINAL ARTICLE

Using mixed fidelity simulation to maximise basic laparoscopic skills training and self-confidence

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Abstract

Background: We aim to show that using tasks with increasing complexity and with increasing fidelity of simulation can maximise students' laparoscopic skills learning, confidence and satisfaction when applied in a single day course. **Methods:** At a laparoscopic skills day, students went through skills simulation with increasing fidelity and complexity. We collected surveys prior to and after the skills day, including demographics, prior experience, and self-confidence scores for key laparoscopic tasks on a 1–10 scale, as well as operative skill data using Inovus augmented reality (AR) simulation software. **Results:** Every area of the students' self-confidence improved, with a mean improvement of 3.42 ($P < 0.001$). The more junior the student, the greater their increase in confidence (mean Pre-Foundation year (FY) = +5.2). Notably, using Inovus AR software we found these skills days to provide an improvement on distance travelled of laparoscopic instrument tips when compared to cohort averages. **Conclusion:** Mixed fidelity simulation is an effective way of rapidly progressing students' skills over the course of a single day. Augmented reality is a way of bridging the gap between basic box-trainer tasks and more complex wet-lab simulation. Capturing operative skills data with software provides an opportunity to focus training to maximise progression.

Keywords: *laparoscopy; surgery; training; augmented reality; laparoscopic surgery; simulation*

Introduction

Within the last decade, laparoscopy has gained significant prominence in the surgical realm, particularly in the US, with the mean annual number of laparoscopic procedures completed by resident surgeons increasing from 23.6 to 135.6 (462%) between 2000 and 2018.[1] Laparoscopy requires a unique skill set, different from that of open surgical skills. In contrast, it involves navigating constraints such as reduced haptic feedback, decreased visual depth perception and restricted movement.[2,3] Another consideration in laparoscopy is the fulcrum effect where the surgeon's hand must move in the opposite direction to that of the tip of the instrument.[4] Finer dissection, identification of correct planes and two-dimensional perception within laparoscopy have also been shown to require more time and experience than traditional surgical skills.[2] Surgeons operate aided via the video monitor and cannot see their hands in the operative field leading to decoupling of the visual and motor axis. Ergonomic considerations involve patient and equipment positioning specifically giving attention to port placement. This decision is both surgeon- and patient-specific; however, general principles should be followed.[5]

Following the COVID-19 pandemic, there has been a steady decrease in the availability of laparoscopic training opportunities for surgical trainees. Popa et al. estimated that the number of days per week that general surgery residents were active in the operating theatre reduced from 5 days pre-COVID-19 to 3 days post-COVID-19, and 77.8% of trainees reported there was no possibility for training in laparoscopic skills outside the hospital.[6] The Royal College of Surgeons (RCS) reports that every month 280,000 surgical training hours are lost due to the European Working Time Directive (EWTD), and doctors starting their surgical training today will have 3000 fewer hours to learn throughout their training, the equivalent of 128 24-hour days. In the UK, logged operative cases by trainees are still lagging behind pre-COVID levels by around one third.[7]

Simulation has become essential in addressing this shortage of live operating hours by familiarising trainees with the handling of laparoscopic instruments, hand–eye coordination and translation of depth perception of the surgical scene from a two-dimensional image. This acquisition of basic skills may represent the trainee being able to go up their learning curve without the need for live cases.[8]

In surgical simulation training, fidelity forms a key consideration within surgical skill acquisition. Logically, more realistic simulation should allow trainees to have faster and higher levels of skill acquisition. A previous systematic review revealed that high-fidelity simulation decreases the operative time and increases performance scores in surgical trainees with limited laparoscopic experience.[9,10]

Extended reality (XR): augmented reality (AR) and virtual reality (VR) may help to bridge the gap between basic, low-fidelity simulation and live surgical practice. AR allows for realistic haptic feedback whilst allowing the assessment of trainee performance via metric recording and builds upon 'fidelity' – a term adapted from audio equipment by the Society of Simulation in Healthcare as a representation of 'realism' within a medical or surgical simulation.[11] A potentially key aspect affecting a trainee's progression up the learning curve is self-confidence when operating. A learner who has greater confidence in their basic abilities may benefit from a greater attentional capacity to learn in live practice, which has naturally declined with reduced training opportunities.[12] Therefore, to improve surgical competence in the theatre, improving trainee confidence may be imperative and this may be achieved outside of live practice, with simulation training.

With reduced access to live operating practice, basic laparoscopic training may be achieved via simulation to reach early-learning-curve competency, allowing for maximal benefit from experience in a theatre environment. Basic, low fidelity laparoscopic training has been shown to be effective at addressing this very early learning curve in basic laparoscopic skill.[13] Introducing higher levels of fidelity to laparoscopic simulation could help the trainee progress up this early learning curve, meaning they can make the most of the relatively scarce live cases.

The ability to record operative metrics with XR techniques can allow for enhanced learning and reflection,[14] as well as more objective assessment.[15] Novel technologies allowing for increased fidelity of simulation, tracking of metrics and objective assessment may provide a solution to current challenges in surgical training. Identifying surrogate markers for progression up the early learning curve is also important in tracking trainee progress. This study explores the effect of using multi-fidelity environment training on trainee operative confidence.

Aim

The primary aim of this study is to assess how mixed-fidelity simulation training affects trainees' confidence in laparoscopic skills over time. We assessed how career level and previous experience can affect any change in their confidence. We also used instrument-tracking software to collect relevant laparoscopic skill performance metric parameters.

Methods

This study was designed to be mapped to the IDEAL evaluation of surgical technology innovations. As a stage 1 study, it is a single-site study pilot, aiming to achieve proof of concept that can be a base to expand on in later stage studies. A proposed pipeline of mapped studies is illustrated in Fig. 1. We designed a single full-day event for 20 participants, illustrated in Fig. 2. The event was designed in three parts with a step-wise increase in fidelity and difficulty. The programme was split into three aspects with a mixture of three short lectures and practical tasks. Participants were Association of Surgeons in Training (ASiT) or Roux Group members with no restriction on career grade or geographical location. They were recruited via public advertisement to membership databases and were invited to participate. Consent was taken from all attendees for their participation in the study and analysis of their anonymised data.

Event design

The first task for participants was basic object manipulation tasks in a box trainer. The tasks included small and large object transfer, hoop and string manipulation, scissor dissection of a disk and laparoscopic suturing. This task lasted for 60 minutes and tasks were based on LapPass assessment tasks.

The second task was a simulated appendicectomy using the AR simulator Inovus LapAR (Inovus Medical, St Helens, UK). Each trainee had the opportunity to go through this AR simulation. The AR procedure included: location of the appendix and movement of small bowel, dissection of the mesoappendix, diathermy control of bleeding, ligation of the appendix and removal of the appendix. Inovus LapAR software captured performance metrics for each participant during this procedure. Metrics captured included: task completion time, distance travelled, handedness (%),

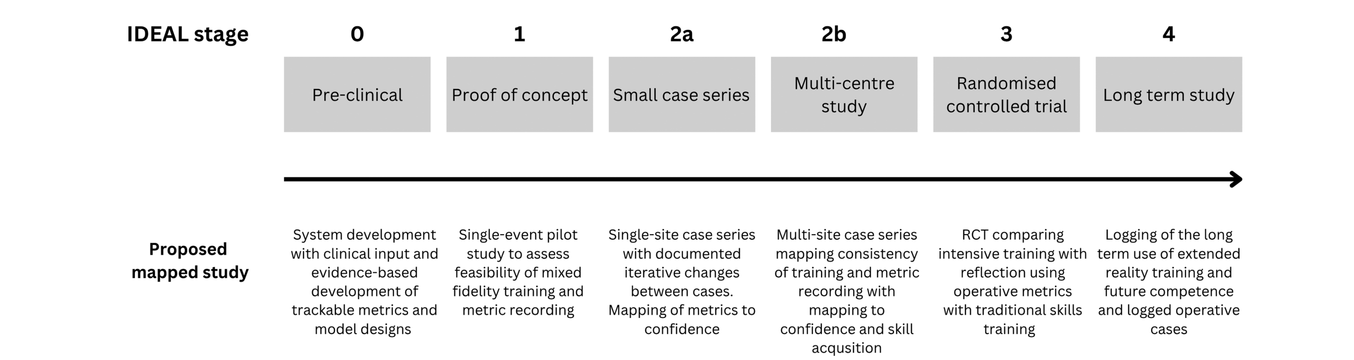

Figure 1. IDEAL framework and proposed mapped studies.

Table 1. Definitions of operative metrics.

Metric	Description
Handedness	Instrument tips are tracked with computer vision. L or R percentage is allocated based on the proportion of time that instrument is tracked as moving, compared to the opposite side.
Acceleration	Instrument tips are tracked with computer vision. Acceleration is calculated as the mean metre per second per second over the procedural time in which the instrument tips are in camera view.
Time of instrument in view	This is the proportion of time that both instrument tips are within the laparoscopic field of vision, for the duration of the procedure.
Smoothness	This is quantified by measuring the jerk, or the rate of change of acceleration. Lower jerk values indicate smoother movements. Measured in dimensionless squared jerk.
Total movement	The cumulative path length travelled by a surgical instrument during a procedure. This is quantified by summing the lengths of all trajectories the instrument takes.

Abbreviations: L: left; R: right.

smoothness (dimensionless squared jerk), acceleration (m/s squared) and time of instruments in view (%). Definitions of each metric are described in Table 1.

The third task was a simulation of a cholecystectomy using a porcine liver and gallbladder specimen within a box trainer. Participants had to use diathermy for dissection and ties for ligating the cystic duct. Each participant had the opportunity to perform and assist one procedure.

Short didactic lectures were delivered between each practical session and included: ‘Principles of Laparoscopy’, ‘Laparoscopic Access and Suturing Technique’ and ‘Safe Cholecystectomy’.

Outcomes

Our primary outcome was to assess changes in self-rated confidence in participants in each surgical skill and knowledge domain. We designed a questionnaire prior to the course with questions that were agreed upon between faculty. In this questionnaire we captured data for: delegate career grade, prior experience of laparoscopic simulation, prior experience of laparoscopic operating and self-rated confidence on a Likert scale of 1–10 in 10 separate domains of laparoscopy. Delegates were asked to complete this survey 5 days prior to the course, immediately after the course (within 24 hours) and 2 months following the course. Core questions remained identical between each survey, including all self-confidence ratings. Secondary questions were added depending on the timing of the survey. Pre-course, immediate post-course and 2 months post-course surveys are available in Supplementary Tables 1, 2 and 3.

Operative metrics were recorded during the AR appendicectomy stage. The software allows for the tracking of: completion time (minutes), handedness, smoothness (DSJ), distance travelled (metres), acceleration (metres per second per second), and proportion of time with instruments in view. These metrics were compared to the recorded global average, which was defined as the mean score of all previously recorded participants on that individual exercise.

Statistical analysis

Differences in self-rated confidence scores were analysed for statistical significance using a two-sided t-test with a statistical significance being taken to be a P value of <0.05. This was calculated between the pre-course and immediate post-course questionnaires. Subgroups of grade (medical student, foundation doctor, surgical trainee) were analysed for mean difference in self-rated confidence score. Subgroups were analysed for difference using the ANOVA statistical test.

Performance metrics were recorded to illustrate the feasibility of the use of metrics in a simulation setting. Mean scores for participants in this study were compared with the mean score of all prior participants on the LapAR database.

Figure 2. Step-wise progression in fidelity session plan.

Table 2. Demographics of participants.

Category		Number	Percentage
Grade	Medical student	7	35%
	Foundation doctor	5	40%
	Core surgical trainee (or equivalent)	8	25%
Gender	Male	8	40%
	Female	12	60%

Formal statistical analysis of difference was not undertaken as the demographic of participants in grade and prior experience was broad.

Results

The response rate for the questionnaires was excellent, with 100% of delegates completing the pre-course and immediate post-course survey; 55% completed the 2 month follow up questionnaire with the results displayed in Supplementary Table 4.

Career grade and prior experience

There was a spread of experience from medical student to CST2 (second year of core surgical training): 20% were medical students, 31% foundation doctors, 31% junior clinical fellows and 19% core surgical trainees (Table 2).

Of the participants, 12.5% had no prior surgical simulation experience, with 87.5% having had basic surgical skills experience; 69% of delegates had laparoscopic simulation experience, the majority of which was basic tasks in a box simulator (50% of delegates). One delegate had experience of virtual reality laparoscopy simulation and no attendees had experience of augmented reality simulation.

We also assessed the maximum level of laparoscopic operative experience; 19.5% had observed in theatre; 68% had assisted in laparoscopic cases, with half of these trainees having assisted in over 10 cases. The remaining 12.5% had completed laparoscopic cases under direct supervision with the trainer scrubbed, with only one delegate having completed over 10 cases.

Confidence in laparoscopy

Self-rated confidence scores for all domains improved between the pre-course and immediate post-course surveys. Mean scores for all domains improved by at least 50%. Each domain had a statistically significant improvement in self-confidence, with all P values <0.05. Mean absolute overall improvement for all domains was +3.42 (95% confidence interval = 3.82–3.03, $P < 0.0001$). All scores are outlined in Table 3.

When self-confidence was analysed in sub-groups dependent on participant grade, all grades experienced a significant improvement in self-confidence in each domain apart from core trainees in 'Principles and considerations of laparoscopy' and 'Assisting in laparoscopic surgery'. There was a general trend that the more junior the grade the proportionally greater the increase in self-confidence was. Table 4 outlines the mean differences between grades of participants.

Operative metrics

Inovus LapAR operative metrics were recorded for all AR appendicectomies. These metrics were compared with pre-existing cohort averages (the mean metric score of all prior attempts from previous users) to identify any significant differences. Delegate statistics are compared with pre-existing cohort averages in Fig. 3. The completion time in our delegates was longer than the pre-existing mean completion time (9 minutes vs 6 minutes). Smoothness and instrument acceleration were improved compared to the pre-existing cohort, with the distance travelled by instruments being improved in our delegates. Handedness parameters were comparable to the live cohort, with no clear dominance of right- or left-handedness.

Table 3. Mean self-confidence scores.

Domain	Mean pre-course confidence score (1–10)	Mean post-course confidence score (1–10)	Mean difference (95% CI)	*P* value
Principles and considerations of laparoscopy	4.35	6.90	+2.55 (1.319–3.79)	0.0002
Assisting in laparoscopic surgery	4.30	6.90	+2.60 (1.29–3.96)	0.0004
Basic laparoscopic skills tasks	3.45	6.80	+3.35 (2.24–4.46)	<0.0001
Access and induction of pneumoperitoneum	2.95	6.25	+3.30 (1.82–4.78)	<0.0001
Laparoscopic suturing	2.00	5.90	+3.90 (2.67–5.13)	<0.0001
Use of safe electro-cautery in laparoscopy (diathermy)	2.40	6.75	+4.35 (2.76–5.94)	<0.0001
Use of advanced energy devices in laparoscopy	2.15	5.50	+3.35 (1.84–4.86)	0.0001
Uncomplicated appendicectomy	2.65	6.40	+3.75 (2.32–5.18)	<0.0001
Difficult appendicectomy	1.85	5.40	+3.55 (2.18–4.92)	<0.0001
Cholecystectomy	2.25	5.80	+3.25 (1.86–4.63)	<0.0001
Overall mean score	2.84	6.26	+3.42 (3.03–3.82)	<0.0001

Table 4. Difference between varying grades.

Domain	FY difference (95% CI, *P* value)	Medical student difference (95% CI, *P* value)	CST difference (95% CI, *P* value)
Principles and considerations of laparoscopy	+2.43 (0.73–4.12) $P = 0.0096$	+3.17 (1.04–5.03), $P = 0.0068$	+2.23 (−0.145–4.59) $P = 0.0627$
Assisting in laparoscopic surgery	+2.43 (0.91–3.95) $P = 0.0052$	+3.55 (1.67–5.42) $P = 0.0013$	+2.3 (−0.84–5.44) $P = 0.1349$
Basic laparoscopic skills tasks	+3.11 (0.76–5.46) $P = 0.0147$	+3.63 (1.41–5.83) $P = 0.0036$	+3.38 (0.66–7.41) $P = 0.0364$
Access and induction of pneumoperitoneum	+3.31 (1.35–5.7) $P = 0.0037$	+4.17 (1.61–6.73) $P = 0.0038$	+2.93 (0.45–6.30) $P = 0.0828$
Laparoscopic suturing	+4.57 (3.19–5.94) $P = 0.0001$	+3.42 (1.58–5.26) $P = 0.0015$	+4.43 (2.26–6.59) $P = 0.0009$
Use of safe electro-cautery in laparoscopy (diathermy)	+4.54 (2.60–6.48) $P = 0.0004$	+4.83 (3.20–6.48) $P = 0.0001$	+4.28 (1.76–6.79) $P = 0.0023$
Use of advanced energy devices in laparoscopy	+3.49 (1.46–5.51) $P = 0.003$	+3.12 (0.96–5.29) $P = 0.008$	+4.22 (2.12–6.33) $P = 0.001$
Uncomplicated appendicectomy	+3.31 (1.35–5.27) $P = 0.0037$	+4.58 (2.80–6.37) $P < 0.0001$	+3.75 (0.86–6.64) $P = 0.0156$
Difficult appendicectomy	+3.71 (2.09–5.32) $P = 0.0005$	+3.62 (1.78–5.50) $P = 0.0009$	+3.95 (1.76–6.22) $P = 0.0029$
Cholecystectomy	+3.66 (2.25–5.06) $P = 0.0002$	+3.0 (0.96–5.04) $P = 0.0074$	+4.7 (2.82–6.58) $P = 0.0002$
Mean overall	+3.6	+5.2	+2.5

Abbreviations: FY: foundation year; CI: confidence interval; CST: core surgical trainees.

Discussion

In this single-site pilot, despite a small sample size, we have shown that including multiple simulation methods in one day is a feasible method of delivering laparoscopic simulation training for a wide range of trainee levels and experience. An introduction to laparoscopy using this combination of training modalities has been successful in improving trainees' laparoscopic confidence, including potentially flattening the early part of the learning curve. For this reason, we focused on self-confidence as the primary outcome to demonstrate how early-stage trainees can benefit from simulation experience prior to exposure to live operating practice in the operating theatre. An increase in confidence in surgical skills may translate to progression up the early learning curve; however, this claim relies on a gap in evidence that we aim to address in a future translatability study. If trainees are able to enter the operating theatre with greater self-confidence this may help to reduce pressures on their attentional capacity and allow for focus on operative aspects, thus allowing them to learn more effectively and safely. This study also demonstrates that, despite little or no prior exposure to AR technology, benefits can be had across multiple domains with no need for technology 'orientation'. Other technology-enhanced learning modalities may also supplement AR by alleviating some of the external pressures on a learner in the operating theatre, such as pre-operative virtual reality simulation of the operative environment or viewing live operative cases to provide the immersion of the non-technical aspects of the operating theatre.[16] Both have been shown to be feasible and advantageous to junior surgical trainees.[17] There was no significant difference in confidence acquisition between trainees with differing levels of prior experience or grade. This suggests that early-career laparoscopic skills training is feasible and may be beneficial to start at an earlier stage.

Recorded operative metrics were compared to mean global scores. The recording of these metrics showed that LapAR can successfully record skill trends and has the potential to compare to a benchmark. This may be beneficial in tracking learning in early-learning-curve training, provide the

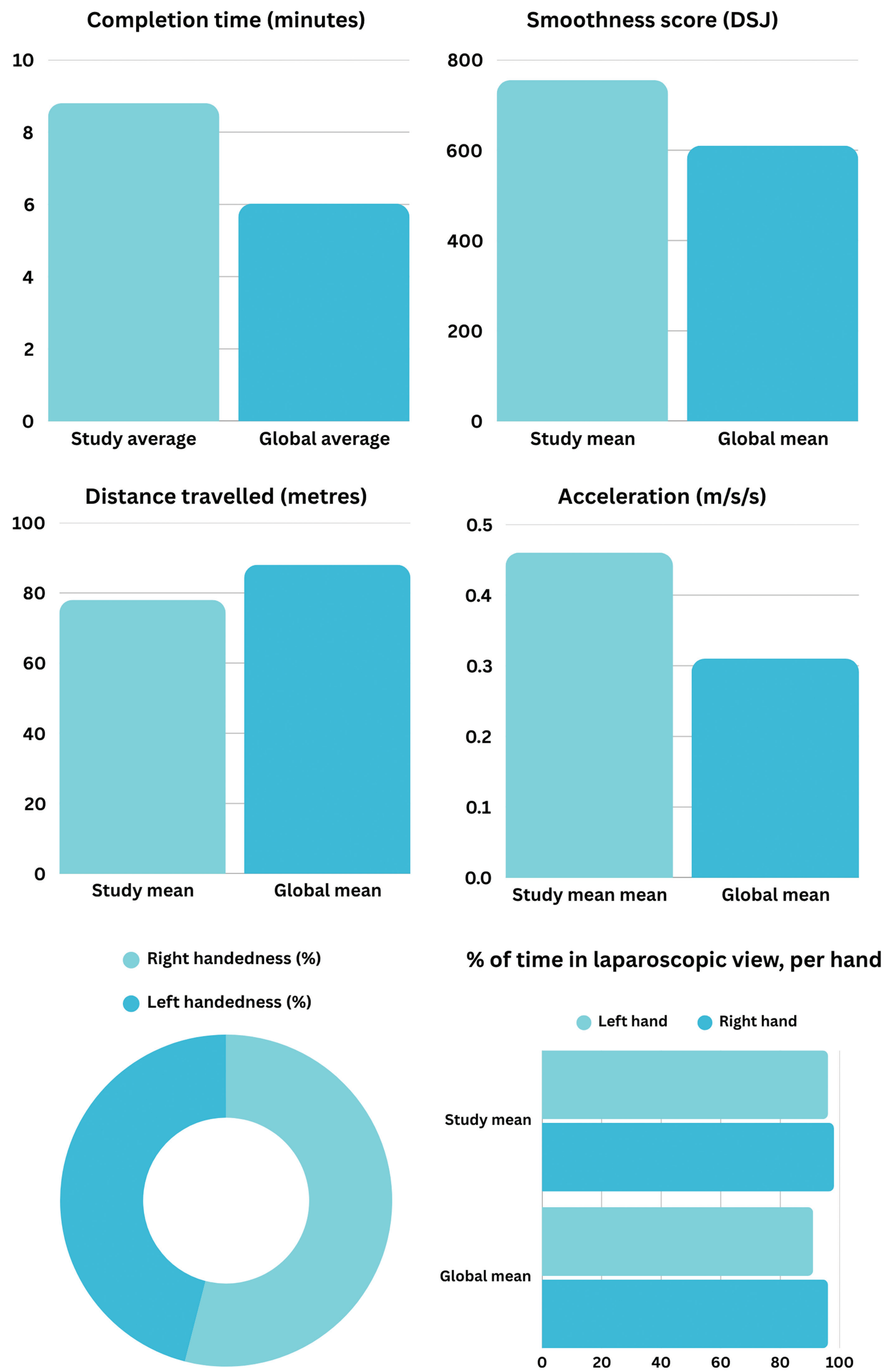

Figure 3. Participant operative metrics compared to 'global average'.

potential for identifying areas or individuals who require further training and allow assessment compared to a predefined benchmark.[9] Objective assessment may provide greater standardisation in the future of laparoscopic training. This could ultimately lead to safer operating and improved patient safety.[10,18]

Limitations

As a single-site pilot study, we only included the experiences of a single group of trainees that were earlier in their careers. Despite recruiting a broad demographic of experiences, our sample size was consequently small. Single-site studies may be dependent on the locally recruited faculty;

however, trainees were from multiple geographic regions and training units. This study was designed to align to the IDEAL surgical intervention evaluation pathway. This pathway is designed to systematically evaluate surgical therapy innovations.[19] With an expansion in technology-enhanced surgical training options, systematic evaluation may help to ensure that implementation is cost-effective, learner centred and safe for patients. This pilot study is aligned to the IDEAL 1 stage.

As we only had the opportunity to record operative metrics at a single point in time, this limited our ability to assess the effects of this course on individual skills. However, it does illustrate the possibility of recording live performance metrics in laparoscopic simulation training. These can help to individualise training in laparoscopy and provide objective feedback to the trainee. Currently, laparoscopic operative performance metrics are novel and mostly not validated. One early study has shown the validity of distance travelled and operative time; however, further research should be undertaken to evaluate other metrics.[20]

We have shown that all participants felt improvements in self-confidence in their operative ability after the training course; however, it is not known how this confidence is affected over time. This may be particularly important in participants who are not able to frequently practice such as medical students. The primary outcome of this study is heavily dependent on the subjective (self) assessments provided by the trainees; as such we only have one view of the learner's subjective ability.

Relation to other laparoscopic training tools

Augmented reality is a novel technology aiming to enhance and improve laparoscopic training. It aims to bridge the gap in fidelity between basic box trainers and cadaveric or live practice. Box trainers have been shown to improve trainee confidence and trainee progression up the early laparoscopic learning curve when taken home. Studies have shown a greater improvement with increased use; however, this may not be a feasible option for large training programmes.[21] Virtual reality training has also been developed to supplement laparoscopic training. A systematic review of VR compared to laparoscopic box trainers, by Selva Raj et al., stated that there was no consensus on which modality had a superior effect on learning curve progression,[22] whereas a systematic review and meta-analysis assessing box training compared to augmented reality laparoscopic skills training suggested the superiority of AR,[23] centred around GOALS and OSATS assessments. Currently there is no clear evidence where technology-enhanced training solutions fit into a surgeon's learning curve and what is the most cost-effective and efficient method of training. Shortening a surgeon's learning curve using metric tracking and improved fidelity could have cost-saving implications with reduced trainer time and faster learning.

Further research

This study has shown the feasibility of a single-day progressive fidelity basic training programme, including novel technology-enhanced training solutions. We have also shown that recording self-confidence and operative metrics in a training event is feasible and may be an alternative or supplementary method compared to commonly used methods such as OSATS. Following the IDEAL pathway, we plan to expand and undertake a stage 2a study: a single-site study refining the use of mixed fidelity, extended reality and operative metric recording in early skills training. A further area of research will be to validate self-confidence rating and its relation to operative metrics and live operative outcomes, creating easily recordable surrogates for early-learning-curve progression.

Understanding the early learning curve of surgical trainees is important to plan targeted intervention and cost-efficient training. It must also be evaluated in a real-world setting along with the impact of time on trainee skill and operative confidence at different grades and levels of experience. The IDEAL framework is well placed to ensure the systematic evaluation of technology-enhanced surgical training interventions prior to implementation into a training programme.

Supplementary material

Supplementary Tables 1–4 are available at https://doi.org/10.5281/zenodo.15700033.

Conflict of interest

At the time of the study, D.R. takes a part-time salary from Inovus Medical. M.H. and F.F. declare no conflict of interests.

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Data availability statement

The data supporting the findings of this article are available from the corresponding author on request.

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