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Research Article

Evaluating the Impact of Augmented-Reality Software on Surgical Training: A Pilot Study

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Abstract

Purpose: Augmented reality has enormous potential to advance surgical training in clinical settings but remains experimental in practice. This study evaluates the use of augmented reality proctoring software (Proximie, London, UK) in video-based operations to expand trainee autonomy and entrustability in the operating room.

Methods: A prospective, randomized, two-armed observational study was conducted at a single institution. Operations enrolled were minimally invasive operations performed by the emergency general surgery service, and endovascular abdominal aortic aneurysm repairs performed by the vascular surgery service. In the experimental group, attendings used the software to guide trainees through cases. In the control group, surgeons supervised cases in their standard practice. The primary end point was the time at which attendings scrubbed and intervened in order to assist trainees. Secondary endpoints were the amount of attending hands-off time, and qualitative data from the SIMPL and OpTrust training feedback tools.

Results: 13 attendings and 12 trainees participated. 38 operations were enrolled, 19 in each group. 84% of trainees were PGY-4 or greater. In the ARPS group, there were trends towards more attending hands-off time and attending-rated trainee autonomy. Entrustability as measured by OpTrust was not significantly different between the two groups.

Conclusions: The use of ARPS during video-based operations may increase attending hands-off time, and improve senior trainee autonomy across a variety of video-based operations. This study is limited by the small sample size. Future trials could implement remote augmented reality software as well as other video-based procedures.

Keywords: Augmented reality; Entrustability; Technical skill acquisition; Autonomy

Introduction

Surgical education is an ever-changing field that requires diligent learners and patient instructors. Current teaching models have not evolved significantly since the days of Halsted. Surgical education still depends heavily on repetition of manual tasks under direct supervision of an experienced surgeon while delivering critical feedback for cultivation of appropriate technique, delivery of critical feedback, and patient safety. Ultimately, the learning surgeon must be able to develop enough confidence in their skills to operate independently. Numerous factors potentially restrict the amount of time that a learner has as the operating surgeon, including duty hour restrictions, high complexity of cases, patient safety concerns, and the ever-evolving advancements of surgical technology that steepen the learning curves of both learners and experienced surgeons. These restrictions make each opportunity to operate vital in achieving the end goal of mastering surgical techniques in order to be able to operate independently. Furthermore, the field's rapid evolution requires innovation for handling new technology, techniques, and restrictions of time and distance. As such, any tool that can enhance a learner's ability to maintain as much "hands-on" autonomy as possible would be essential in building confidence and accelerating learning. Numerous adjuncts for the cultivation of operative skills have been described [1-5], but none address the challenge of maximizing trainee autonomy in the operating room.

The last few years have seen the dawn of augmented reality software that has tremendous potential for use in the field of surgery, particularly in surgical education [5]. One such concept is adapting augmented reality platforms to superimpose an instructor's direction over in-room video monitors, as has been demonstrated in robotic surgical consoles [6]. This is of particular relevance, as there has been a significant increase in the volume of minimally invasive techniques by nearly 50% [7], almost all of which utilize some form of video-based technology [5,6,8-13]. Proximie® (London, UK) is an example of an Augmented Reality Proctoring Software (ARPS) solution which provides such capabilities. The impact of augmented reality on enhancing trainee autonomy has never been studied. Scientifically demonstrating efficacy and practicality of the use of ARPS in surgical education has immense implications in maximizing trainee autonomy and entrustability as well as providing an opportunity to eliminate the need for "in-house" or "in-person" instructors.

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Materials and Methods

This study is a prospective, randomized, two-armed trial. Participants were general surgery residents, vascular surgery fellows, and their supervising attending general and vascular surgeons, respectively. Attendings and trainees were enrolled on an opt-in basis. Participants underwent a ten-minute training session to review the functionalities and tools of ARPS, and an opportunity for review with questions and troubleshooting was available before starting each case. A moderator who was familiar with ARPS was available for the duration of the case for assistance with software if needed. Operations enrolled were any laparoscopic operation on the emergency general surgery service, and cannulation of the contralateral gate during endovascular aortic aneurysm repairs at Oregon Health and Science University. Patients involved in these operations were counseled regarding the study design and written consent was obtained, regardless of which arm they were randomized. Prior to each operation, baseline data was collected for each trainee, attending surgeon, and patient. Trainees identified their Postgraduate Year (PGY) of training, number of prior operations of the same CPT code for the case being studied, and whether they intended to enter academic practice or private practice after graduation. Cases were randomized into the experimental arm, in which the attending surgeon proctored the studied portion of the case using ARPS; or the control arm, in which the attending surgeon coached the trainee through the case in their standard practice. The attending in each case used their discretion to scrub in to deliver direction or to take over an operation or parts of an operation, regardless of whether they were in the trial or control arm. The total duration of the studied portion of each operation, whether the attending took over the case, and the total duration of attending control of a case were recorded. Attending Hands-Off Time (HOT) was calculated as the time without attending takeover divided by total time in the case. In order to capture case difficulty, trainee performance, and perceived degree of autonomy, the trainee and attending each completed a System for Improving and Measuring Procedural Learning (SIMPL) [14], survey following the operation, metrics detailed in Table 1. Additionally, the audio and video captured were analyzed using the OpTrust tool [15], in order to capture degree of trainee and attending entrustability, metrics detailed in Table 2.

Preoperative participant demographics, operative time, attending takeover, attending HOT, and survey outcomes were analyzed using a Wilcoxon rank-sum test for continuous variables and Fisher test for binary outcomes.

Table 1: SIMPL survey questions and answer choices provided to trainees and attendings after completion of an operation.

Question	Answer choices
How much guidance was provided for the majority of the procedure?	1 - Show and tell
	2 - Active help
	3 - Passive help
	4 - Supervision only
What was the trainee's performance for the majority of the procedure?	1 - Unprepared/critical deficiencies
	2 - Inexperienced with procedure
	3 - Intermediate performance
	4 - Practice-ready performance
	5 - Exceptional performance
How complex was the case relative to similar procedures?	1 - Easiest 1/2
	2 - Average
	3 - Hardest 1/3

Results

A total of 12 trainees and 13 attending surgeons participated in the study. 84% of trainees were PGY-4 or greater. There were no differences in number of prior pertinent operations performed (p=0.43) or career goals (p=0.5) for trainees, and no differences in attending prior pertinent operations (p=0.4). 38 cases were studied, 28 of which were general surgery cases, and 9 of which were vascular surgery cases. 19 cases were randomized into the ARPS arm, and 18 were in the control group. There were no differences in patient ASA scores or number of a patient's prior pertinent operations (p = 0.34, 0.48, respectively). The patients in the ARPS group were significantly older than in the control group (61 *vs.* 51, p=0.04). General surgery cases enrolled included laparoscopic appendectomy, laparoscopic cholecystectomy with or without intraoperative cholangiograms, diagnostic laparoscopy for reduction of internal hernia, laparoscopic paraesophageal hernia repair, thoracoscopic decortication, laparoscopic diverting loop colostomy, robotic colostomy takedown, and robotic cholecystectomy. Vascular cases enrolled were Endovascular Aortic Aneurym Repairs (EVAR) and Fenestrated Endovascular Aortic Aneurysm Repairs (FEVAR). There were no intraoperative complications as a result of using the software.

The primary outcome measured was whether or not an attending took over a case, which occurred in 25% of cases in the ARPS arm, and 35% of cases in the control arm. This did not reach statistical significance, with p=0.48. In the ARPS group, percentage of time with trainee in control of the operation, or attending HOT, was 86% compared to 75% in the control group, which approached significance with p=0.13. Reasons for attendings taking over included trainee request, trainee lack of progress, and attending preference due to complexity of a case. Attending takeover was never driven by failure or malfunction of ARPS. The remaining secondary outcomes as measured by the SIMPL and OpTrust tools did not reach statistical significance between the ARPS and control groups, as detailed in Tables 3 and 4, respectively.

Discussion

Increasing complexity of surgical technique adds a degree of challenge in ensuring trainees can possess the confidence required to practice and operate independently in a relatively short amount of time. This trend is apparent in general surgery as minimally invasive and endovascular operations become more common [7,16]. Ensuring that the trainee is the primary operator as often as possible is key for building the confidence necessary to become a safe surgeon, but is increasingly challenging as operations become more complex. The main objective of this study was to test the feasibility of implementing ARPS in a safe way such that a trainee could be an independent operator. The software is an intuitive interface that required little time for user adaptation, and was minimally disruptive for the surgical team. Furthermore, use of ARPS did not result in any intraoperative complications. While it seemed that there was a trend towards more attending HOT and increased trainee autonomy, our analysis shows that ARPS is not superior in these domains to standard in-person attending supervision. Due to the absence of a power analysis as this was a pilot study, we cannot claim that the use of ARPS is equivalent to standard surgical education practices in the operating room. Additionally, we cannot be sure that there was a true difference which was missed due to inadequate sample size. Several limitations are present in this study. Firstly, a larger sample size may have revealed

Table 2: OpTrust tool metrics utilized for evaluation of attending and resident level of communication.

Domain (Score)	Low Entrustability (1)	Medium Entrustability (2)	High Entrustability (3)	Full Entrustability (4)
Types of questions asked	Attending: Does not ask resident questions for a majority of the case	Attending: Asks leading or closed questions that require yes/no response from resident for majority of the case	Attending: Extends knowledge with open-ended questions	Attending: Is approachable as a consultant to support resident's higher-level thinking and problem solving
	Trainee: Does not ask faculty questions for majority of the case	Trainee: Asks questions related to anatomy and foundational knowledge for majority of the case	Trainee: Asks questions about upcoming steps in the procedure/procedural flow	Trainee: Asking questions of additional learner; asking questions of faculty for goal-oriented feedback; no questioning necessary when fully independent
Operative Plan	Attending: Sought minimal to no input from resident for intra-operative steps/plan.	Faculty: Asks trainee for steps/plan, but did not include trainee's suggestions	Attending: Asks resident for steps/plan and integrates trainee ideas	Attending: Directly followed trainee's plan
	Trainee: Minimal input provided intraoperatively	Trainee: Suggests some steps	Trainee: Forward-thinking and suggests tentative plan for entire case	Trainee: Provides full operative plan which is then carried out
Instruction	Attending: Faculty identifies landmarks for majority of case or provides step-by-step instructions	Attending: Asks trainee to provide landmark identification; provides close instruction and instrument orientation	Attending: Provides minimal instruction during portions of case and only provides step-by-step instruction when trainee is struggling	Attending: Provides feedback on refinement of technical skills, but otherwise provides no instruction
	Trainee: Pauses frequently and awaits instruction	Trainee: Steady progression of case and/or cues faculty for moderate instruction because of lack of progress	Trainee: Fully advances case by requesting or receiving minimal instruction	Trainee: Progresses ca se efficiently with no instruction from faculty
Problem solving	Attending: does not include trainee in problem solving and/or takes away the case after a near miss or error and never returns the case	Attending: Problem solves with resident by showing and telling what the attending would do, but the attending fixes the problem	Attending: Raises caution and/or problem solves with trainee and then has trainee solve the problem with step-by-step instruction from faculty	Attending: Follows the trainee's lead in solving the problem by integrating the trainee's ideas/suggestions
	Trainee: Does not participate in problem solving or does not understand what comes next in procedure	Trainee: Identifies potential solutions, attending addresses problem	Trainee: Brings forward solutions or concerns and fixes the problem with attending guidance	Trainee: Identifies problem and implements solution with no guidance from attending
Leadership by trainee	Attending: Performs majority of case and allows trainee minimal opportunity to participate	Attending: Provides significant cueing and leads for the majority of the case	Attending: Allows trainee to progress with minimal cueing up until critical parts of the case and then supports the trainee's lead with close instruction	Attending: Is in supervisor role when trainee progresses the case until no more progress is made
	Trainee: Is in first assist role and primarily observes, but is also allowed to work in briefly	Trainee: Demonstrates an increasing ability to perform different basic parts of the operation with close faculty supervision	Trainee: Is able to safely execute majority of steps in case with attending in first-assist role	Trainee: Leads operation and recognizes when to seek help/advice

Table 3: Analysis of SIMPL Survey results completed by trainees and attendings. Ratings expressed as a mean for each group.

	ARPS	Control	p value
Trainee SIMPL Survey Analysis			
How much guidance was provided for the majority of the procedure?	3.23	3.07	0.33
What was the trainee's performance for the majority of the procedure?	3.46	329	0.4
How complex was the case relative to similar procedures?	2.17	2.07	0.4
Attending SIMPL Survey Analysis			
How much guidance was provided for the majority of the procedure?	3.375	2.88	0.076
What was the trainee's performance for the majority of the procedure?	3.56	3.63	0.4
How complex was the case relative to similar procedures?	2.13	2.25	0.31

a significant difference in HOT or trainee autonomy between groups. A future study using this model would include a power analysis to establish baseline measures of trainee autonomy as captured in this study. Another factor that may have clouded the data was the decision to enroll a wide variety of operations in the study. This aspect of the study design was intended to capture as broad of a scope of surgical practice and participants as possible, and to identify the feasibility of using ARPS in a training setting. Due to the small sample size and relatively short duration of the study, we were unable to capture a large enough volume of cases with varying degrees of difficulty to appropriately stratify a type of operation for which ARPS is best suited. It could be considered in future studies to concentrate on one particular operation to minimize confounding variables. ARPS has many potential applications within the realm of surgical training that have not been addressed in this study. While the scope of this study included general and vascular surgery, ARPS could be integrated into any video-based procedural system, including interventional radiology and cardiology, microvascular surgery, gastrointestinal or urogynecologic endoscopy, and arthroscopy. In addition, it may be used to maximize surgical simulation training. For trainees in all of these fields, ARPS may offer an alternative means to ensure maximal procedural hands-on time. Further studies should be performed

Table 4: Analysis of OpTrust tool scores, represented as averages.

	ARPS	Control	p value
Trainee			
Types of questions asked	3.19	3.29	0.47
Operative Plan	3.25	3.24	0.47
Instruction	2.88	3	0.34
Problem solving	2.94	3.11	0.28
Leadership by trainee	3.5	3.41	0.3
Attending			
Types of questions asked	3.19	3.29	0.27
Operative Plan	3.13	3.05	0.5
Instruction	3.125	3.05	0.44
Problem solving	3.19	3.35	0.29
Leadership by trainee	3.25	3.18	0.44

to evaluate the feasibility of implementing ARPS in these settings. Another key scenario in which ARPS could be very advantageous is in the realm of remote proctoring and consulting. In regards to the use of ARPS for remote proctoring and consulting, this ARPS platform has previously been used for expert surgical advice in the setting of a complex hand reconstruction in Gaza [8]. This proof-of-concept indication for ARPS has yet to be studied further, but could present the opportunity for extending the reach of field experts in surgical subspecialties to rural or underserved areas in need of proctoring of complex procedures.

Conclusions

ARPS is a safe, easy-to-use platform that can be implemented in video-based operations to guide trainees in surgical technique. There may be a positive impact on trainee autonomy and entrustability when ARPS is used, although more research is needed to confirm this preliminary finding. Further studies may also evaluate other video-based procedures outside of general and vascular surgery, as well as the feasibility of its use as a remote proctoring platform.

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