A comparison between augmented reality and traditional in-person teaching for vascular anastomotic surgical skills training

Rebecca Stoner, MD,[a] Manal Ahmad, MRCS,[b] Sajan B. Patel, BcS,[c] Adrian Cowell, PhD,[d] Thomas Hurkxkens, PhD,[e] Louis Bastrot, MD,[f] Caroline Caradu, MD, PhD,[f] Dimitri Amiras, MD,[g] *and* Joseph Shalhoub, MD, PhD,[b] *London, UK; and Bordeaux, France*

ABSTRACT

Background: Augmented reality (AR) superimposes computer-generated content to a real-world environment through multitudinous devices, and is used across multiple training fora. Its use in vascular surgery education is yet to be formally investigated. The aim is to assess feasibility and effectiveness of remote teaching of vascular anastomosis skills enhanced by AR in the form of the HoloLens2 Head-Mounted Display technology with traditional in-person skills teaching. A remote trainer used video, gestures and images superimposed over participants' field of vision via the HoloLens2 to teach the skills.

Methods: Twenty-eight participants underwent a preassessment performing an end-to-end vascular anastomosis on an artificial vessel. They were allocated randomly to an AR or in-person group, and underwent two teaching sessions. Individuals were asked to complete a postsession feedback form and assessment (video recorded and anonymized). The videos were marked by two blinded, independent assessors using the Objective Structured Assessment of Technical Skills (OSATS) scoring.

Results: There was an overall improvement in both cohorts in OSATS score after the intervention by +7.083 in the in-person group and +8.275 in the AR. Independent *t* test was performed and a *P* value of .422 was obtained, indicating no statistically significant difference in the change in OSATS scores when comparing the skills teaching received in-person with that through AR.

Conclusions: Remote teaching enhanced by AR is feasible and effective for the teaching of vascular surgical anastomosis skills and noninferior to in-person teaching. There is scope for development of the use of AR in vascular surgical skills training. (JVS-Vascular Insights 2024;2:100032.)

Keywords: Education; Surgical skills; Augmented reality; Postgraduate education; Undergraduate education

Augmented reality (AR) is a technology whereby real-world environments and interactions are modified through computer-generated (CG) content in the form of CG sensory stimuli. In contrast, virtual reality (VR) is an artificial experience simulated solely in a synthesized world.[1] Both AR and VR fall on the spectrum of the reality-virtuality continuum first proposed by Milgram and Kishino.[2]

From the Chelsea and Westminster Hospital, Lord Wigram Office, Chelsea and Westminster Hospital,[a] the Department of Vascular Surgery, Imperial College Healthcare NHS Trust,[b] the Department of Medicine, Imperial College London,[c] the Department of New Media and Innovation, Imperial College London,[d] and the Digital Learning Hub, Imperial College London,[e] London; the Department of Vascular Surgery, Bordeaux University Hospital,[f] Bordeaux; and the Department of Radiology, Imperial College Healthcare NHS Trust,[g] London.

Correspondence: Rebecca Stoner, MD, General Surgery Trainee, Chelsea and Westminster Hospital, Lord Wigram Office, Chelsea and Westminster Hospital, 369 Fulham Rd, SW10 9NH, London, UK (e-mail: rebecca.stoner3@nhs.net).

The editors and reviewers of this article have no relevant financial relationships to disclose per the Journal policy that requires reviewers to decline review of any manuscript for which they may have a conflict of interest.

2949-9127

https://doi.org/10.1016/j.jvsvi.2023.100032

AR in medical education is usually provided in the form of a head-mounted display worn by the user.[3] It allows surgical procedures to be assimilated into segments which can be taught, practiced, and evaluated.[4] Although VR allows a trainee to practice a particular skill, AR lends itself to more realistic simulation by its ability to blend CG content with physical experiences. For example, the Microsoft HoloLens2[5,6] used in this study, used CG audio and video via a headset, to alter the reality of the user. The HoloLens2 is a holographic hands-free computer coupled with software to superimpose CG images over the real world.[5] This facilitates learners to gain experience, build confidence, and gain feedback on surgical skills that, although standardized, can also be individualized to a learner's needs and becomes an excellent resource in training and formative assessment.

In surgical training, AR has been widely cited for uses in different specialties and different skills, with good results in skill development[7-9] owing, in part, to the realistic depiction it offers in terms of visual, tactile, and handling characteristics.[7,10] Despite this, literature on the use of AR in vascular surgery skills teaching is limited.

Our aim for this study was to assess AR using the HoloLens2 device and Remote Assist software as a method of teaching vascular anastomosis skills compared traditional, in-person teaching. We aimed to assess the feasibility of AR in this context, as well as comparative effectiveness and experience of trainers and trainees compared to in-person training. The primary outcome assessed is the paired change in the validated Objective Structured Assessment of Technical Skill (OSATS) scores,[11-13] comparing the two groups. Secondary outcomes include trainer and trainee satisfaction.

Our null hypothesis proposes that there is no significant difference in the paired OSATS scores after intervention with either traditional in-person teaching or teaching using AR.

METHODS

Ethical approval was gained through the Imperial College Education Ethics Research Process. Participants were recruited through email and word of mouth. Inclusion criteria consisted of medical students, postgraduate year 1 doctors (PGY-1/foundation doctors) and other junior doctors who did not have prior experience with performing a vascular anastomosis. Exclusion criteria included doctors of PGY-5 grade (registrar) or more senior and prior experience of performing a vascular anastomosis.

A power calculation was not performed, because there were no studies found in the literature review using the same skill and assessment method. Based on similar studies, a sample size of 20 participants was selected.[14-16]

Written informed consent was obtained from all applicants, and each was anonymized by allocation of a random CG participant number. Accepted applicants were then asked to complete a preassessment feedback form (Appendix I), relating to their experience and confidence in performing a vascular anastomosis.

Participants then underwent a 20-minute preassessment, where they were asked to perform an end-to-end vascular anastomosis on an artificial vessel mounted on a jig (Fig 1). They were provided with all the standard instruments usually present on a vascular tray, including a basic surgical set, a Castroviejo needle holder, Ryder needle holder, Gerald forceps and 5/0 double-ended Prolene sutures. Each was also provided with printouts illustrating step-by-step instructions on how to perform an end-to-end anastomosis (Appendix II). Videos of the preassessment exercise were obtained by recording the artificial vessel and the gloved hands of the participants to ensure bias reduction; videos were labelled with the respective anonymized participant number.

Participants were then randomized as either an AR group or a traditional in-person group before the initial training session by the investigators. This was done by assigning a method to alternating sessions throughout the training day, and allocating students to the sessions (who were unaware of the method assigned) based on their availability. They were blinded to their group's allocation until after the preassessment.

Fig 1. Set up of jig and instruments.

Participants in both groups then underwent two separate 40-minute teaching sessions in groups of no more than three trainees, taught by a consultant vascular surgeon with expertise in medical education and training in providing feedback. Participants were placed in the same room, at separate tables, with their own set of surgical instrument trays and artificial vessel. During the sessions they received teaching, feedback, and support in performing vascular anastomoses.

Participants in the AR group were provided a HoloLens2, which had already been set up and were asked to wear it (Fig 2). They were then asked to accept a video call through Microsoft Teams from the trainer who was in a remote location. The trainer was set up with three separate laptops and was connected on three separate calls during the teaching sessions with the different trainees, which they would mute in turn depending on which person the trainer was engaging with (Fig 3). For the in-person teaching group, instruction was provided in the traditional format, whereby the trainer would circulate in the room to supervise the task and provide feedback to each participant individually. The trainer was involved in the design of the educational content and assessment of the sessions. The trainer also received a short brief at the beginning of the project, about how to use the HoloLens. At least one person with more

Fig 2. Participant wearing HoloLens head-mounted display (HMD). They are able see the vessel and jig and their trainer superimposed over their field of vision.

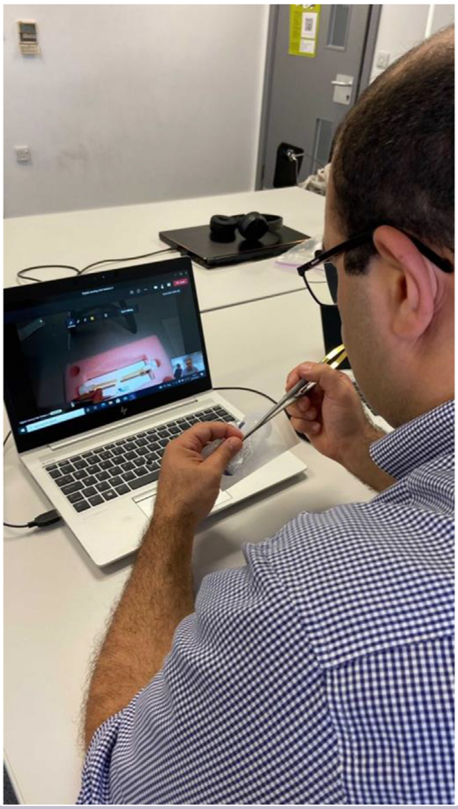

Fig 3. The trainer is able to see their trainee's point of view, through a camera on the head-mounted display (HMD).

experience with the HoloLens was available on site, for any troubleshooting or questions.

After completing two teaching sessions, the individuals were asked to complete a postsession feedback form (Appendix III) and then complete a 20-minute postassessment exercise on the same jigs (Fig 4). These assessments were once again recorded by collecting footage of the artificial vessels and participants' gloved hands. Videos for all participants in both preassessments and postassessments, were obtained using a video camera mounted on a stand.

Before being marked, all videos had audio and participant numbers removed, and videos were renamed using a web-based random number generator. Videos were marked using the OSATS scoring system (Table I). The validated OSATS score has been found to be a feasible, effective, and reliable tool to assess surgical skills, with acceptable construct and content validity. It has been used in different surgical specialties, including vascular surgery to assess competency.[12,13] This consists of seven separate competencies which are marked from a range of 1 to 5 for each category, including respect for tissue, time and motion, instrument handling, knowledge of instruments, use of assistants, flow of operation and forward planning, and knowledge of specific procedure. The minimum achievable global score is 7 and the maximum achievable global score is 35.

For the purposes of this study, six of the seven competencies were assessed. Use of assistants was not assessed, because the trainees performed the assessments independently thus the minimum achievable global score was 6 and the maximum achievable global score was 42.

Two different assessors marked the videos independently, blinded to the AR or in-person group allocation of the participant and whether the video was a preteaching or post-teaching assessment. They each marked two 20-minute videos per participant—approximately 18 hours per assessor. Assessors were consultant vascular surgeons with experience in medical education, who were provided with the OSATS marking scheme and the anonymized and randomly ordered. The assessors were not involved in the teaching of the sessions. An average of both assessors' scores was taken for each video. Interassessor variability was analyzed. The difference for each participant's score in the preintervention and postintervention assessments was calculated. Eight videos were duplicated, and a new random video number assigned, to assess intra-assessor variability.

The feedback results from the assessors and the participants were also tabulated and compared. The study and results were reported and submitted in line with CONSORT guidelines.

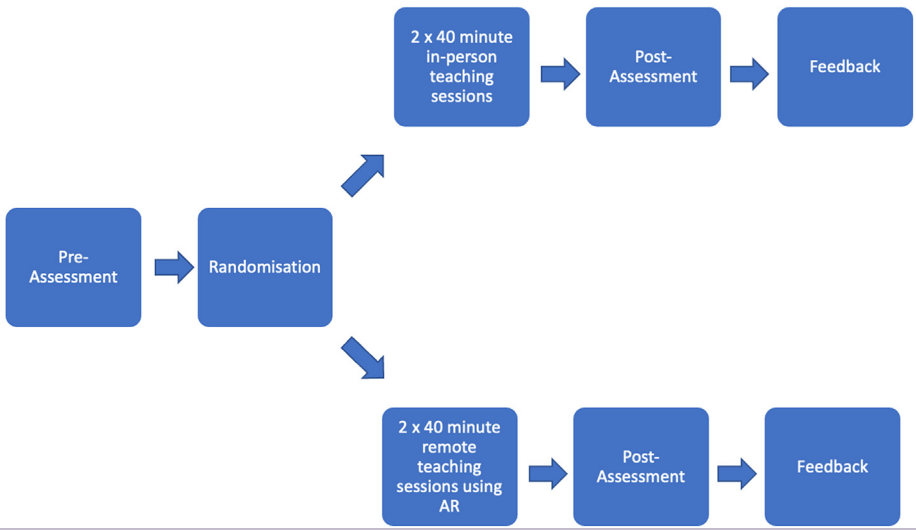

Fig 4. Study design. *AR,* augmented reality.

RESULTS

Twenty-eight participants volunteered and were eligible to contribute to the study. Fifteen identified as male and 13 identified as female. Fourteen were medical students, 9 were PGY-1 and 5 PGY-2 or -3. Of the 28 participants, 15 were allocated to traditional in-person teaching. Of the traditional in-person cohort, three participants did not attend both sessions and were, therefore, excluded from the data analysis. Of the 13 participants randomized to AR, 2 were excluded from the data analysis for not completing both sessions and 1 was excluded for poor assessment video quality unsuitable for assessment (Fig 5).

There was an overall improvement in both cohorts in OSATS score after the intervention, by +7.083 in the traditional in-person teaching cohort and +8.275 in the AR teaching cohort (Table II). The Shapiro-Wilk test did not show a significant departure from normal distribution for both the AR group and traditional in-person group data (W = 0.896; $P = .196$ and W = 0.905; $P = .182$) (Fig 6). The F-test was performed to assess for variance within the groups, and both samples were found to have equal variance (F = 1.7748; $P = .3659$). Independent *t* test identified no statistically significant difference in the change in OSATS scores when comparing the skills teaching received in-person with that through AR ($P = .422$).

Comparing each of the individual surgical competencies assessed by the OSATS score, there was no statistically significant difference in mean difference in score in respect for tissue ($P = .6570$), time and motion ($P = .0954$), instrument handling ($P = .2169$), knowledge of instruments ($P = .3936$), flow of operation and forward planning ($P = .9823$), or knowledge of specific procedure ($P = .8356$), between the two groups. There was also no significant difference found between participants of the same grade between groups (medical student $P = .1685$, PGY-1 $P = .2491$; PGY-2 and -3 cohort too small to calculate).

To quantify agreement between assessors and, therefore, assess for interobserver variability, the difference in scores between the two independent assessors was analyzed using intraclass correlation coefficient; Cronbach's alpha was 0.811 ($P<.001$)[18]; therefore, interobserver bias was considered negligible.

Intraobserver variability between the average scores of the original videos and their duplicates was compared. Of the eight duplicated videos, two were excluded owing to poor quality making videos unsuitable for assessment. Therefore, a total of six pairs of assessment averages were compared. Intraclass correlation coefficient Cronbach's alpha was 0.941 ($P = .001$), indicating a very good strength of agreement; hence, intraobserver bias was considered negligible.

Of the 28 participants, presession feedback forms were completed by all 13 of the AR cohort and all 15 of the in-person traditional cohort, postsession 1 and postsession 2 feedback forms by 12 and 13 of the AR cohort, respectively, and 15 and 9 of the in-person cohort (Table III).

The difference in agreement with the statement. "I am familiar with the steps of performing a vascular anastomosis" increased by 2.77 compared with 2.27 ($P = .1621$) for the AR cohort and in-person cohort, respectively, after 2 sessions. The difference in agreement with the statement, "I am familiar with the instruments required to perform a vascular anastomosis" increased by 2.85 and 2.42 ($P = .1356$), "I am familiar with the technique required to perform a vascular anastomosis" by 2.77 and 2.22 ($P = .1994$), and "I am confident in performing a vascular anastomosis" by 2.77 and 2.31 ($P = .0458$) for the AR cohort and in-person cohorts, respectively.

In the AR cohort, the majority of participants agreed or strongly agreed that the HoloLens2 was easy to set up,

Table I. Objective Structured Assessment Technical Skills (OSATS) scoring system[17]

Competency	1	2	3	4	5
Respect for tissue	Frequently used unnecessary force or caused damage by inappropriate use of instruments		Careful handling of tissue but occasionally caused inadvertent damage		Consistently handled tissue appropriately with minimal damage
Time and motion	Many unnecessary moves		Efficient time/motion, but some unnecessary moves		Economy of movement and maximum efficiency
Instrument handling	Repeatedly makes tentative or awkward moves with instruments		Competent use of instruments, but occasionally appeared stiff or awkward		Fluid with instruments and no awkwardness
Knowledge of instruments	Frequently asked for wrong instrument or used inappropriate instrument		Knew the names of most instruments and used appropriate instrument for the task		Obviously familiar with the instruments required and their names
Use of assistants	Consistently placed assistants poorly or failed to use assistants		Good use of assistants most of the time		Strategically used assistants to the best advantage at all times
Flow of operation and forward planning	Frequently stopped operating or needed to discuss next move		Demonstrated ability for forward planning with steady progression of operative procedure		Obviously planned course of operation with effortless flow from one move to the next
Knowledge of specific procedure	Deficient knowledge. Needed specific instructions at most steps		Knew all important aspects of the operation		Demonstrated familiarity with all aspects of operation

comfortable to use, and that the video and audio from the HoloLens2 were clear. The majority of participants in this cohort strongly agreed that they were able to clearly understand instructions from their trainer, found it beneficial that their instruments were not taken over by their trainer, and found that feedback was clear. The majority disagreed that they felt it was detrimental that they could not see their trainer and did not experience side effects from the HoloLens. The majority of students strongly agreed or felt neutral about preferring to have been taught this skill in person. However, the vast majority strongly agreed that this modality of training would be a good alternative if in-person teaching was restricted. Negative comments received mainly focused on technical problems related to the HoloLens2 equipment ("call dropping, video stops working, video quality"), side effects ("headache"), and some difficulty in understanding instructions ("difficult to explain hands-on things in words"). Most of the feedback was positive ("Flexibility. Comfortable. Less pressure than in person. Trainer can explain from our shared perspective, less confusion about left/right etc.", "The trainer can see my work without myself being interrupted," "Great that trainer can see what you do from their eyes"). Suggestions for improvement included having a monitor to be able to see the trainer, adjusting table height for comfort and improving the technology of the HoloLens2.

In contrast, the majority of the in-person cohort strongly agreed that it was beneficial that they could see their trainer and the majority disagreed that they would have preferred to have this teaching carried out via HoloLens2. Interestingly, numerous feedback comments about the negative perceived aspects of this method included having to travel to the location and not being able to receive this teaching internationally. Participants strongly agreed that their trainer was able to reference to

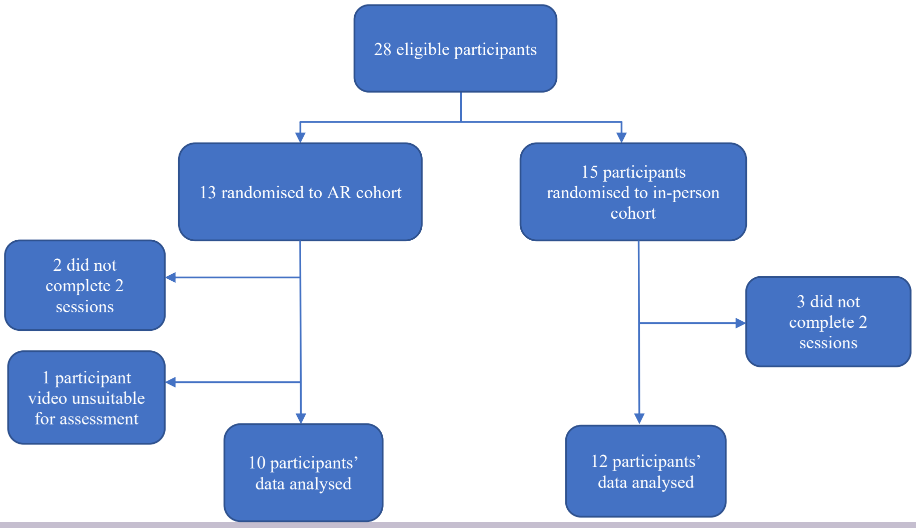

Fig 5. Allocation of eligible participants to the augmented reality (*AR*) and in-person arms of the study.

part of their grafts, and they were able to understand instructions and feedback. The majority were neutral about the statement, "my trainer occasionally took over my instruments." Positive comments about this method of teaching included "real-time feedback," "able to get the attention of trainer." and "trainer being able to point to things," which were also possible through the AR method. Positives limited to this modality included "no technical difficulties," "building rapport through in-person contact," and "taking over instruments."

DISCUSSION

The results of this study confirm that using AR via the HoloLens2 to teach vascular anastomosis skills was equally as effective as traditional in-person teaching in all domains studied, including respect for tissues, efficiency, handling instruments, flow, and knowledge of the procedure. The trainees' perceived effectiveness was also comparable, with trainees finding both modalities acceptable. This finding supports the literature, which demonstrates effectiveness in improving surgical skills in other specialties such as ophthalmic surgery, orthopedics, and laparoscopic surgery,[7-9,19] as well as acceptability by trainees, which has also been demonstrated in specialties such as neurosurgery, urology, and general surgery.[7,10,20]

Training modalities may be assessed against five factors—face validity (resemblance to a real situation),

Table II. Change in Objective Structured Assessment Technical Skills (*OSATS*) scores comparing the augmented reality (*AR*) and in-person teaching

Difference in OSATS score following in-person teaching intervention	Difference in OSATS score after AR teaching intervention
2.5	11
3.25	3
3.5	6.5
5	12
6.5	11
7.5	6
8	9.5
8	10
9.75	12.5
10	1.25
10.5	-
10.5	-
Mean score change	
+7.083	+8.275

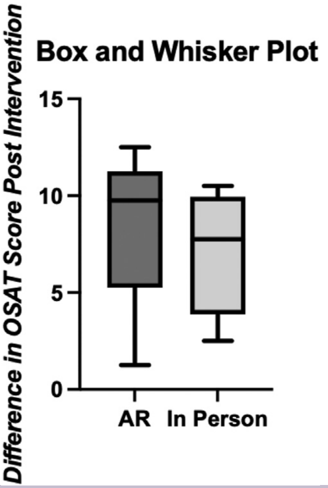

Fig 6. Box and whisker plot demonstrating the distribution of Objective Structured Assessment Technical (*OSAT*) score changes comparing the augmented reality (*AR*) and in-person teaching arms of the trial.

Table III. Mean self-assessment agreement scores reflecting perception between the augmented reality (*AR*) and in-person (*IP*) cohorts before the intervention and after teaching

	No. of participants		I am familiar with he steps of performing a vascular anastomosis.		I am familiar with the instruments required to perform a vascular anastomosis.		I am familiar with the technique required to perform a vascular anastomosis.		I am confident in performing a vascular anastomosis.	
	AR	IP	AR	IP	AR	IP	AR	IP	AR	IP
Preassessment mean	13	15	1.69	2.07	1.77	2.13	1.62	2.00	1.23	1.47
Post session 1 mean	12	15	4.00	4.07	4.17	4.27	3.92	3.93	3.33	3.20
Difference after session 1			2.31	2.00	2.40	2.13	2.30	1.93	2.10	1.73
Preassessment 2 mean	13	9	4.46	4.33	4.62	4.56	4.38	4.22	4.00	3.78
Post session 2 mean			2.77	2.27	2.85	2.42	2.77	2.22	2.77	2.31

Likert scale 1-5 (strongly disagree to strongly agree).

content validity (positive evaluation of the educational value by experts), construct validity (how accurate the assessment is in terms of experience of the user and results they obtain), concurrent validity (how it compares to established training methods), and predictive validity (how the skills translate to real practice).[21] This study assessed concurrent validity and compared it with the current established method of training, which is in-person teaching. The teaching of surgical techniques such as vascular anastomosis is often based on the concept of social constructivism first proposed by Vygotsky[22] owing to its apprentice-based nature whereby a more knowledgeable other—a teacher, peer, or CG expert—facilitates the transition to competency by traversing the zone of proximal development via a defined social interaction, such as a teaching session. When teaching, the use of similar instruments and equipment along with the type of feedback can further play into the high-fidelity replication of the actual environment, allowing participants to develop in this environment and facilitating integration within the actual theatre environment at a later time. For this reason, the study also indirectly looks at predictive validity. Considering the Cognitive Load theory, which suggests that cognitive processing systems are finite in capacity and are often cited in performing procedural skills and complex tasks,[23] in the design of this study, the distribution of teaching across two sessions dispersed the formative feedback, thus decreasing cognitive load for novice learners in the hope of more effective learning[24] in both study arms.

This study was limited to teaching novices alone, to ensure that those participating in the study had no prior experience in performing vascular anastomoses. With junior trainees, trainee-trainer rapport has not yet been established and not seeing the trainer may not influence training significantly. Furthermore, these trainees would certainly benefit from not having their instruments taken over as they begin to become comfortable with using them. It is interesting to consider more experienced trainees, who work closely with their trainers and may have established a mentorship relationship with them.[25] It may also be that, as they need fine tuning of their technique, they may find that their trainer adjusting their instruments is useful to improving performance.

The OSATS score has been validated for surgical skills, which have been found to correlate to years of surgical experience. OSATS allow training to be performed in a standardized way[26] and without risk to patients, while still obtaining feedback and gaining experience in practical skills. Some disadvantages quoted include bias when marking, which is why intra-assessor and interassessor variability was minimized through the study design, assessed for, and significant contribution confirmed to be absent.

The improvement in performance improved by 7 to 8 points on the OSATS with no significant difference being found between the groups. It has been reported that dedicated training sessions in vascular surgery skills do lead to improvement of skills, both in group settings and one on one.[12,13] The OSATS improvement found in this study is higher than quoted in other studies (3-5 points).[12,13] This could be due to subjectivity in rating; however, it further supports that time spent training with a tutor, including through AR, is effective in anastomoses training.

The results from the anonymized assessments found improvement in skills through AR teaching to be comparable with in-person teaching, with feedback from students suggesting that they also feel that they have improved similarly. With a limited number of clinical hours and increasing clinical commitments, hands-on training and formal teaching are limited. Having effective remote options for teaching practical skills could be beneficial in terms of efficiency and time management.

Although the reported satisfaction with the AR method was comparable with the in-person method, the majority would still have preferred to have this teaching done in person. Similarly, the in-person cohort also disagreed that they would have preferred to have this teaching done via AR. This finding may be related to not having experience with using AR for teaching previously. From the feedback from participants and experience of the investigators, several technical problems incurred while using the HoloLens2, such as connectivity, videos being interrupted, and insufficient battery life. For this reason, additional support was needed in person to assist with technology. It is interesting that the AR cohort felt it did not matter that they could not see their trainer, but the in-person cohort reported that they preferred to see their trainer. It has been found that one of the predictors of trainee satisfaction is trainer rapport.[27] It is unclear how much rapport is impacted with virtual communication, particularly if the trainer and trainee have not yet worked together.

Unique points from the AR group that were found to be valuable included the trainer being able to see from the learner's point of view and not having the instruments taken from them, which may aid in efficiency for teaching practical skills. The opportunity to have the perspective of the operator/trainee documented in the literature, and has been found to be realistic and helpful to training,[28] and this feature should be maximized when using it for training.

Building in-person rapport, which was mentioned by the in-person group, can possibly still be achieved through AR, but may need increased experience and familiarity with the technology to facilitate. It is also important to note that, unlike other educational technologies, AR is interactive and allows participants to ask questions and gain individualized feedback in real time.

The results of this study were encouraging that AR is a suitable and convenient alternative to teaching vascular anastomosis skills. AR could be further used in multiple vascular teaching scenarios including remote provision of endovascular planning and training, remote trauma settings and complex procedures requiring multidisciplinary input. It can also be used in other surgical skill training and in time with improving technology could be used to integrate the haptic feedback to learn skills using solely AR overlay instruments to reduce the need for physical objects and instruments allowing the development of surgical skills independent of location or surgical equipment. This would entail virtual or simulated instruments, being superimposed over the real model, which would be manipulated to perform the skill being learnt. The technology available for AR continues to improve, becoming more affordable, reliable, efficient, and accessible, and will inadvertently reflect frequent use of this technology in he future.

Future work in this area could focus on expanding the use of AR to other skills in vascular surgery and other specialties, adapting technology to be able to teach larger groups of students at the same time and increasing the availability of the technology. Limitations in this study included technical issues with the hardware and software such as connectivity and battery life. More work is needed to ensure that the available technology is more user friendly, more suitable for purpose and requires less on-site support. The cost of AR technology, as well as the personnel needed to support the use, is not negligible. The cost of the HoloLens2 is advertised on the Microsoft website as £3349 per headset, and there is also a yearly subscription that needs to be paid. The programs used were not at a cost. During the training sessions, it was necessary to have one person on site with experience using the HoloLens and this person was often the person setting up the sessions. It would be useful and interesting to assess the cost of this compared with the cost of time and travel related to in-person training. Trainees were also uncertain of AR, having never been exposed to it before. With increasing familiarity and experience, the acceptability of AR should improve and may become considered a standard alternative to traditional teaching. Participants in both cohorts underwent training sessions in the same room, with a possibility that those in the in-person cohort could have overheard some of the feedback, comments, or questions between the trainer and other participants, with the AR cohort being able to overhear only the participant side. However, the distance between tables was far enough that participants were largely out of hearing range, and anything heard would have been limited. The aspect of learning from peers' questions and mistakes was lost from both cohorts owing to separating participants. This functionality could be added in the future to AR teaching, by having the trainer on the same call with all participants as opposed to separate individual calls. In this way, trainees can overhear and watch corrections being made at the same time while they learn the same skill.

Simulation training and VR have been well-documented in the literature for the teaching of practical skills in medical education,[5,17,29-31] with successful outcomes and acceptability. The technology in AR is more novel and less available, and therefore it may take some time for its use and evidence to grow and be comparable to VR. Benefits of AR include translating the learning experience into a more realistic context, as there is a mix of both CG content as well as real objects, which provides a more representative experience.

CONCLUSIONS

AR can provide an effective method for teaching vascular surgical skills and can lead to objective improvement in task-specific evaluations that are comparable with in-person teaching and offers further scope for expansion in its applicability in the specialty. Research assessing its use in future surgical education, in different vascular skills and different surgical specialties, is certainly supported by the results of this paper.

AUTHOR CONTRIBUTIONS

Conception and design: RS, SP, AC, TH, CC, DA, JS
Analysis and interpretation: RS, MA, SP, AC, CC, LB, DA, JS
Data collection: RS, MA, SP, AC, TH, DA, JS
Writing the article: RS, MA, JS
Critical revision of the article: RS, MA, SP, AC, TH, CC, LB, DA, JS
Final approval of the article: RS, MA, SP, AC, TH, CC, LB, DA, JS
Statistical analysis: RS, MA, SP, JS
Obtained funding: Not applicable
Overall responsibility: RS

DISCLOSURES

None.

REFERENCES

1. McKnight RR, Pean CA, Buck JS, Hwang JS, Hsu JR, Pierrie SN. Virtual reality and augmented Reality—translating surgical training into surgical technique. *Curr Rev Musculoskelet Med.* 2020;13:1—12.
2. Milgram P, Takemura H, Utsumi A, Kishino F. Augmented reality: a class of displays on the reality-virtuality continuum 1995;. 1995;2351: 282—292.
3. McKnight RR, Pean CA, Buck JS, Hwang JS, Hsu JR, Pierrie SN. Virtual reality and augmented reality—translating surgical training into surgical technique. *Curr Rev Musculoskelet Med.* 2020;13:663—674.
4. Bartlett JD, Lawrence JE, Stewart ME, Nakano N, Khanduja V. Does virtual reality simulation have a role in training trauma and orthopaedic surgeons? *Bone Joint Lett J.* 2018;100:559—565.
5. HoloLens 2-Overview, Features, and Specs | Microsoft HoloLens [Internet]. Accessed August 23, 2024. https://www.microsoft.com/en-gb/hololens/hardware.
6. Dynamics 365 remote assist. *Microsoft.* 2021;6:4.
7. Botden SM, Buzink SN, Schijven MP, Jakimowicz JJ. ProMIS augmented reality training of laparoscopic procedures face validity. *Simulat Healthc.* 2008;3:97—102.
8. Menozzi M, Ropelat S, Köfler J, Huang Y. Development of ophthalmic microsurgery training in augmented reality. *Klin Monbl Augenheilkd.* 2020;237:388—391.
9. Ropelato S, Menozzi M, Michel D, Siegrist M. Augmented reality microsurgery: a tool for training micromanipulations in ophthalmic surgery using augmented reality. *Simulat Healthc.* 2020;15:122—127.
10. Alaraj A, Charbel FT, Birk D, et al. Role of cranial and spinal virtual and augmented reality simulation using immersive touch modules in neurosurgical training. *Neurosurgery.* 2013;72(suppl_1):A115—A123.
11. Martin JA, Regehr G, Reznick R, et al. Objective structured assessment of technical skill (OSATS) for surgical residents. *Br J Surg.* 1997;84:273—278.
12. Wilasrusmee C, Lertsithichai P, Kittur DS. Vascular anastomosis model: relation between competency in a laboratory-based model and surgical competency. *Eur J Vasc Endovasc Surg.* 2007;34: 405—410.
13. Pandey VA, Black SA, Lazaris AM, et al. Do workshops improve the technical skill of vascular surgical trainees? *Eur J Vasc Endovasc Surg.* 2005;30:441—447.
14. Sidhu RS, Park J, Brydges R, MacRae HM, Dubrowski A. Laboratory-based vascular anastomosis training: a randomized controlled trial evaluating the effects of bench model fidelity and level of training on skill acquisition. *J Vasc Surg.* 2007;45:343—349.
15. Bath J, Lawrence P, Chandra A, et al. Standardization is superior to traditional methods of teaching open vascular simulation. *J Vasc Surg.* 2011;53:229—235.e2.
16. Schwartz S, de Virgilio M, Chisum P, et al. A prospective randomized study assessing optimal method for teaching vascular anastomoses. *Ann Vasc Surg.* 2014;28:1087—1093.
17. Menozzi M, Ropelat S, Köfler J, Huang Y. Development of ophthalmic microsurgery training in augmented reality. *Klin Monbl Augenheilkd.* 2020;237:388—391.
18. Altman DG. *Practical statistics for medical research.* CRC press; 1990.
19. Logishetty K, Western L, Morgan R, Iranpour F, Cobb JP, Auvinet E. Can an augmented reality headset improve accuracy of acetabular cup orientation in simulated THA? A randomized trial. *Clin Orthop Relat Res.* 2019;477:1190—1199.
20. Dickey RM, Srikishen N, Lipshultz LI, Spiess PE, Carrion RE, Hakky TS. Augmented reality assisted surgery: a urologic training tool. *Asian J Androl.* 2016;18:732.
21. Barsom EZ, Graafland M, Schijven MP. Systematic review on the effectiveness of augmented reality applications in medical training. *Surg Endosc.* 2016;30:4174—4183.
22. Prawat RS. Social constructivism and the process-content distinction as viewed by Vygotsky and the pragmatists. *Mind Cult Activ.* 1999;6: 255—273.
23. Van Merrienboer JJ, Sweller J. Cognitive load theory and complex learning: recent developments and future directions. *Educ Psychol Rev.* 2005;17:147—177.
24. Shute VJ. Focus on formative feedback. *Rev Educ Res.* 2008;78: 153—189.
25. Smeds MR, Huynh C, Thrush CR, Moursi MM, Amankwah KS. Effects of mentorship on graduating vascular surgery trainees. *Ann Vasc Surg.* 2017;44:234—240.
26. Niitsu H, Hirabayashi N, Yoshimitsu M, et al. Using the objective structured assessment of technical skills (OSATS) global rating scale to evaluate the skills of surgical trainees in the operating room. *Surg Today.* 2013;43:271—275.
27. Ghosh P, Satyawadi R, Prasad Joshi J, Ranjan R, Singh P. Towards more effective training programmes: a study of trainer attributes. *Ind Commerc Train.* 2012;44:194—202.
28. Rochlen LR, Levine R, Tait AR. First person point of view augmented reality for central line insertion training: a usability and feasibility study. *Simulat Healthc.* 2017;12:57.
29. Ropelato S, Menozzi M, Michel D, Siegrist M. Augmented reality microsurgery: a tool for training micromanipulations in ophthalmic surgery using augmented reality. *Simulat Healthct.* 2020;15:122—127.
30. Botden SM, Buzink SN, Schijven MP, Jakimowicz JJ. ProMIS augmented reality training of laparoscopic procedures face validity. *Simulat Healthc.* 2008;3:97—102.
31. Tang KS, Cheng DL, Mi E, Greenberg PB. Augmented reality in medical education: a systematic review. *Can Med Educ J.* 2020;11:e81.

Submitted Aug 14, 2023; accepted Oct 30, 2023.