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ORIGINAL ARTICLE

VITAL: an IDEAL stage 2b feasibility study of a randomised controlled trial evaluating whether virtual reality technology can improve surgical training in Sierra Leone

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Abstract

Background: Training surgeons is costly and resource intensive, often requiring extended periods of expert supervision. Virtual reality (VR) has shown potential in enhancing surgical skill acquisition, but its use in low- and middle-income countries (LMICs) remains limited. This study aimed to evaluate the feasibility of using smartphone VR for surgical training in LMICs. **Methods:** We conducted a prospective randomised controlled feasibility study involving surgical trainees recruited from a government teaching hospital in Freetown, Sierra Leone. Participants were randomised 1:1 VR vs non-VR and received a 2-day hands-on course on lower limb amputation. The VR group received additional VR training consisting of two 30-minute modules with narrated live surgery videos. Feasibility outcomes included recruitment rates, VR intervention adherence, fidelity and acceptability. **Results:** A total of 30 participants were randomised, 15 to the VR group and 15 to the control group. The recruitment period lasted 2 days, and 29 participants (96.7%) completed the course. The VR intervention had high fidelity and acceptability, with 100% of participants completing the intervention. There was no unblinding. Compared to the control group, the VR group reported statistically significantly higher engagement during the hands-on course. **Conclusion:** Our findings suggest that smartphone VR is technically feasible for surgical training in LMICs, and may improve engagement and perceived learning. With minor modifications to the intervention and assessments, a larger-scale trial is feasible. These results highlight the potential for VR to address the challenges of surgical training in LMICs, where access to expert supervision and costly training resources may be limited.

Keywords: *LMIC; low- and middle-income countries; virtual reality; feasibility studies; surgeons*

Introduction

Training surgeons is expensive, time-consuming and relies on skill acquisition over a high volume of cases with expert supervision.[1] The World Health Organization (WHO) estimates a global shortage of over 7.2 million healthcare providers and highlights that significant investment in healthcare training is required to achieve Universal Health Coverage (UHC) by the year 2030.[2] This shortage disproportionally affects low- and middle-income countries (LMICs), with the lowest workforce densities often found in the world's poorest countries.[2] New training technologies could address this unmet need.

Performing surgery is an all-encompassing experience requiring simultaneous use of prior knowledge, practical skills, situational awareness and real-time problem solving. Simulation and immersive technologies, such as virtual reality (VR), provide a safe and scalable training environment that can combine these elements.[1] VR is a type of immersive technology that gives the user experience of a totally different, simulated reality, involving a head-mounted display with or without handheld controllers. The use of simulation enhances the acquisition of basic skills and knowledge in advance, reserving limited training time in theatre to cover more complex material.[3] Several studies have explored these technologies to enhance surgical training and have

demonstrated efficacy.[4–7] There is limited evidence to inform the implementation of these within surgical training in LMIC settings. One study from Rwanda demonstrates the feasibility of simulation-based training to improve operative skills when delivered as a brief training intervention. The study highlights that LMICs have specific drivers to adopt simulation technologies, including high trainee–trainer ratios, limited number of operating rooms and reliance on short-term training from visiting international trainers.[8]

Whilst educational opportunities may be limited in LMICs, the use of smartphones, although modest, appears to be growing in prevalence and this may open up the possibility of exploiting this resource as a surgical training tool.[9] A training intervention using VR on smartphones that are already prevalent in the population may have powerful disruptive potential in these settings. The aim of this study was to assess the feasibility and acceptability of smartphone-based VR for surgical training in Sierra Leone.

Materials and methods

Study setting

The study was conducted in Freetown, Sierra Leone, as a collaboration between the Leeds NIHR Global Health Research Group in Surgical Technologies, Connaught Hospital and CapaCare Non-Governmental Organisation. Study participants were either government-employed surgical trainees or surgical officers in the CapaCare Surgical Training Programme.[10]

Lower-limb amputation

Lower-limb amputation was chosen as the topic for the hands-on training course and VR module. This is a frequently performed operation in Sierra Leone and other LMICs where the rates of trauma and chronic lower-limb infection are particularly high.[10–14] The pre-course learning and the hands-on course focused on the indications, perioperative management and operative technique for lower-limb amputation.

Trial design

The study was designed as an assessor-blinded, parallel group, feasibility randomised controlled trial, following the CONSORT extension statement checklist for feasibility studies.[15] This design reflects an IDEAL Stage 2b evaluation study of a surgical innovation.[16] Ethical approval for the study was obtained from the University of Leeds School of Medicine Research Ethics Committee (MREC 19-016) and the Sierra Leone Scientific Ethics Review Committee, Ministry of Health and Sanitation Sierra Leone. To be eligible, participants had to be a current surgical trainee or graduate of a government or CapaCare Surgical Training Programme and able to attend a 2-day training course.

Recruitment took place 7 days before the hands-on training course. All participants provided written informed consent. Participants were allocated 1:1 to either VR training or non-VR training using stratified block randomisation using a random number generator. It was not possible to blind participants, but assessors were blinded to allocation. Stratification factors included previous surgical experience and training programme affiliation (Government or CapaCare). Baseline demographic data included current training grade, number of lower limb amputations observed/performed, and previous use of VR and other video assisted learning tools.

As the trial was designed to assess the feasibility and intervention fidelity, a power calculation was not considered appropriate. A sample size of 30 (15 in each arm) was deemed sufficient based on recommendations of 10–20 participants per group to assess feasibility outcomes.[17,18]

Intervention description

All participants in both the VR and non-VR groups had access to pre-course learning and a hands-on training course. The pre-course learning for both the VR and non-VR groups included printed written material, consisting of information and illustrations about the technique of lower-limb amputation in the form of a booklet. In addition, those randomised to the VR group received pre-course VR training. The pre-course material was available 7 days prior to a 2-day hands-on course for all participants.

Trainees randomised to the VR group were given VR Shinecon 2.0 headsets that convert smartphones into head mounted displays (manufacturer: VR Shinecon, Dongguan, China; Model number: 1629_VRSHINECON) and access to two 30 min VR modules, which covered below-knee amputation (BKA) and above-knee amputation (AKA). The amputation modules were based on live operations previously filmed in collaboration with Medical Realities Ltd (London, UK), and narrated by a consultant vascular surgeon. The modules focussed on critical anatomy and operative steps during amputation. There were two video feeds, one from a 360-degree Vuze+ camera (Humaneyes Technologies Ltd, Israel) that was mounted on a tripod and positioned at the foot end of the operation table. A 'surgeon's eye view' that captured the detail of the operative field was filmed using a Sony (Tokyo, Japan) HVR-Z5E digital camcorder mounted on a Hague multi-jib held above the table.

Participants were trained in how to use their smartphones with the headsets and how to navigate through the modules.

The training modules were accessible through an application which was free to download to their smartphones from the App Store or Google Play Store. If the participant did not have a compatible phone, or no phone at all, Samsung (Seoul; South Korea) Gear VR headsets with Samsung Galaxy S9 phones were made available to loan for the study period.

All participants were instructed to engage with their pre-course learning material at least once prior to the hands-on course. Data on pre-course learning engagement was collected via self-reported questionnaires after the hands-on course. All participants were invited to attend the 2-day hands-on training programme. The course was delivered using an interactive approach employing a combination of didactic lectures, practical demonstration and hands-on simulation covering the critical steps of above- and below-knee amputation including skin marking, neurovascular bundle ligation, and bone shaping and division. The course was delivered by consultant surgeons from the UK and Sierra Leone. On completion of the study, all study participants were given a headset with access to the VR modules.

Outcome measures

The primary outcomes were participant recruitment and retention rates, and VR intervention fidelity. Recruitment success was defined as 80% of eligible participants agreeing to be enrolled in the study. Successful retention was defined by less than 10% attrition rate. Successful VR intervention fidelity was defined as at least 80% of the VR group successfully completing the VR modules at least once measured by participants self-reporting their completion on questionnaires after the hands-on course.

Secondary outcomes explored key aspects of the study design:

- Rate of unblinding.
- Adherence to protocol and group contamination rate (contamination is defined as participants in the non-VR group accessing the VR intervention).
- Intervention fidelity, defined as the inability to use or access VR when required.
- The acceptability of VR, and whether it increased engagement in learning [via a modified Web-based Learning Tools (WBLT) Evaluation Scale].[19,20]
- Skill acquisition via OSATS assessment score (objective structured assessment of technical skills) and knowledge acquisition via written multiple-choice questions (MCQs).

OSATS assessment scores are validated measures of hands-on procedural skill acquisition that can be applied to a range of clinical skill domains. The assessors of the OSATS and MCQ assessments were blinded to study group allocation. It was not possible to blind the research team or the participants to group assignment.

Statistical analysis

Participant baseline characteristics are summarised descriptively. The number of participants completing each component of the training programme was recorded. Quantitative outcome measures are presented using summary statistics for the whole study cohort and by allocated group.

Results

Thirty eligible participants consented and were randomised to the VR group ($n = 15$) or the non-VR group ($n = 15$). Figure 1 displays the CONSORT trial participant flow diagram. The mean age was 32.3 years (SD = ± 5.8). Twenty-four (80%) were male, representing a male-to-female ratio of 4:1. The mean years of surgical experience was 2.7 years (SD = ± 2.24). The majority were general surgical trainees ($n = 26$; 86.7%). Twenty-eight participants (93.3%) owned a smartphone, and all had previously used educational applications on their device. Only two participants (6.67%) had prior experience of immersive technology. Baseline characteristics are summarised in Table 1.

Feasibility outcomes for the 14 items used to evaluate methodological issues for feasibility research are presented in Table 2. These items are derived from previous methodological research.[21,22]

Eligibility, recruitment and randomisation

Between 1 and 8 November 2019, 42 trainees were screened for eligibility to the study. Two trainees did not meet the inclusion criteria; one was a medical student, and one could not attend the hands-on course. Eight trainees were not enrolled because they were outside the recruitment period. A total of 32 trainees met the inclusion criteria, but one declined to consent as they felt unable to commit to the pre-course learning, and one declined consent but did not want to express a reason. Recruitment and consent processes were deemed successful as 30 eligible trainees consented and were randomised to either the VR group ($n = 15$) or the non-VR group ($n = 15$). The outcome assessors (MCQ and OSATS markers) and course faculty were blinded to participant allocation, which was maintained throughout the study. There was no cross-over of participants between the two intervention groups.

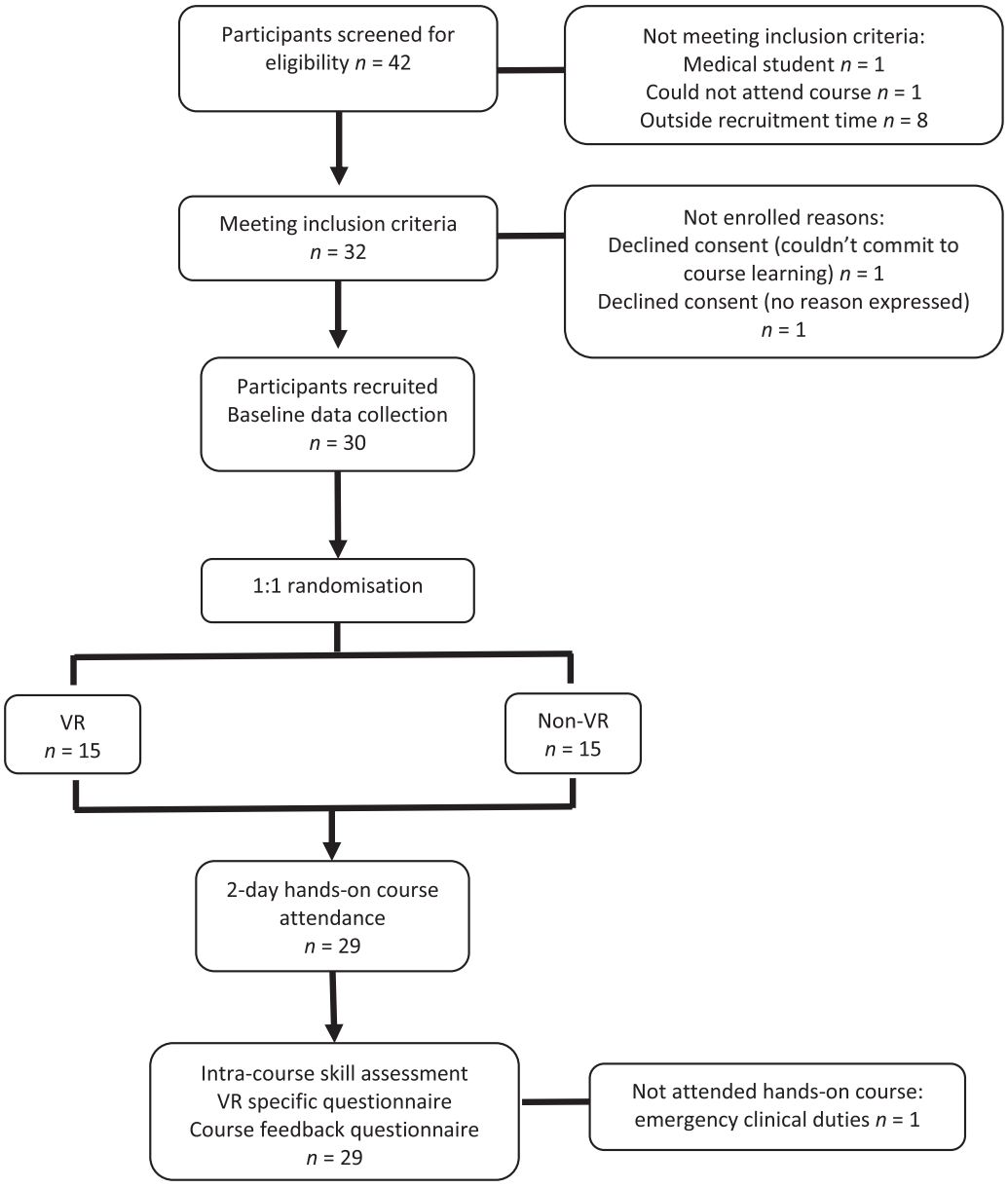

Figure 1. VITAL Trial CONSORT trial participant flow diagram.

Adherence to the intervention

Of the 30 recruited participants, 29 (96.7%) successfully completed the 2-day hands-on course. One had to withdraw shortly before the hands-on course due to emergency clinical duties. Intervention adherence exceeded the pre-specified success rates with 100% of participants completing the VR at least once. Six participants (40%) completed the VR modules more than once. Twelve (80%) of the VR group could access the modules on their own mobile phones; one did not have a smart phone, and two did not have the necessary in-built hardware (accelerometer) and were provided with a loan device. The VR modules were completed a total of 21 times by the 15 participants in the VR group. Only on one occasion (4.7%) was a participant unable to access the VR due problems opening the application on their phone, which was later resolved. In the non-VR group, all participants reported reading the pre-course booklet at least once. In the VR group, 12 (80%) used the pre-course booklet alongside the VR modules.

Outcome assessment

All participants who attended the hands-on course ($n = 29$) completed the outcome assessments; 100% completed the modified web-based learning tools (WBLT) evaluation, the

Table 1. Baseline participant characteristics

Variable	All participants $n = 30$	VR group $n = 15$	Non-VR group $n = 15$
Experience (years; mean ± SD)	2.7 ± 2.24	2.53 ± 2.07	2.87 ± 2.47
Age (years; mean ± SD)	32.3 ± 5.8	31.7 ± 4.0	32.9 ± 7.3
Sex M:F	24:6	11:4	13:2
Government training *N* (%)	21 (70%)	10 (66%)	11 (73%)
CapaCare Surgical Training Programme *N* (%)	9 (30%)	5 (33%)	4 (27%)
Speciality			
General surgery *N* (%)	26 (87%)	13 (87%)	13 (87%)
Obstetrics and gynaecology *N* (%)	3 (10%)	2 (13%)	1 (7%)
Trauma and orthopaedics *N* (%)	1 (3%)	0	1 (7%)
Smartphone use			
Owned a smartphone *N* (%)	28 (93%)	14 (93%)	14 (93%)
Number of educational apps on smartphone	2.8 (IQR 2–4)	3.2 (IQR 2–4)	2.4 (IQR 1–3)
Previous use of immersive technologies *N* (%)	2 (7%)	0	2 (14%)
Previous use of immersive technologies *N* (%)	2 (7%)	0	2 (14%)

course feedback questionnaire, the MCQs and the OSATS. The results of the MCQ and OSATS assessments are presented in Table 3. The VR group had larger mean scores achieved for both OSATS and MCQs. This study was not powered to identify effect for these measures.

When asked about engagement in learning and perceived fulfilment of learning objectives, the VR group recorded increased perceived learning before the hands-on course and increased engagement with the pre-course learning. The VR group also recorded higher engagement in the hands-on course itself. A full breakdown is presented in Appendix 1.

Discussion

Despite the technical challenges of working in low resource settings, this study has shown that it is feasible to conduct an IDEAL Stage 2b study of smartphone VR surgical training in LMICs. VR appears acceptable to surgical trainees with high rates of engagement before and during a hands-on course. Given the high engagement in learning and completion of the course, intervention adherence and fidelity were deemed to be a success.

A strength of this study is that it investigates the implementation of VR interventions within a simple IDEAL Stage 2b study, employing short data collection time points. The study investigated how VR could be used alongside existing training courses to enhance the effect of these opportunities in a blended learning approach. VR is a platform technology and the specific content delivered is wide ranging, potentially covering several specialties and procedures. Another strength is the exploration of smartphone-based VR. Some immersive technology applications require prohibitively expensive hardware, such as the mixed-reality platform HoloLens by Microsoft.[23] While these technologies may bring benefits for certain applications, this adds an additional barrier to implementation in terms of cost and access to extra equipment. Although a recent report demonstrated that smartphone adoption was modest and varied across countries within Sub-Saharan Africa, exploring technologies that more closely align to existing hardware may improve adoption.[9] The rate of smartphone adoption is increasing in many countries, and in our study most participants owned a device. Indeed, even if they did not currently own a smartphone, our participants were digitally knowledgeable and engaged well with the VR technology, requiring only minimal instruction. Smartphone ownership is more frequent in younger, more educated populations, possibly explaining the high rates in our study.[9] Reliable internet and modest speeds are required for many technology-enhanced learning tools. Again, while the rate of internet use is growing, the majority of Sub-Saharan African populations have no or limited access.[24] A headset is still an additional item of equipment required to convert the smartphone into a head-mounted display for VR application, but these are becoming very low cost, reducing this barrier to adoption.[25]

Limitations of this study are also recognised. It is not possible to draw conclusions about the educational effectiveness of VR technology for surgical training. Indeed, the present study was not powered or designed to test the hypothesis that VR improves surgical training. Hypothesis testing in feasibility studies is inappropriate and firm conclusions cannot be drawn either way from an underpowered study.[22,26] Although no contamination was reported in our study, trainees were enthusiastic and eager to engage with the VR technology. It is possible that the VR was shared between

Table 2. Summary of findings against 14 methodological issues for feasibility research

Methodological items	Findings	Evidence
1. What factors influenced eligibility and what proportion of those approached were eligible?	Ineligibility was only found in two screened participants: due to not including medical students and being unable to attend the hands-on course.	30 agreed to participate, only two screened declined to consent. More may have consented if sample size was larger.
2. Was recruitment successful?	Yes. Recruiting success was defined as 80% of eligible participants agreeing and being recruited into the study. A larger sample size is possible with a larger hands-on course capacity and recruitment window.	30 out of 32 (93.8%) eligible participants agreed to take part and were recruited. There were many more that may have been eligible had a larger recruitment window been used.
3. Did eligible participants consent?	Yes. The majority of participants agreed to consent.	Only two did not wish to consent.
4. Were participants successfully randomised?	Yes. Randomisation processes worked well.	Table 1 shows that baseline group differences were minimal.
5. Were blinding procedures adequate?	Yes. Assessors of MCQs and OSATS and course faculty were blinded to assignment throughout.	Assessors and faculty were not present during pre-course learning and participants did not disclose their assignment during the course.
6. Did participants adhere to the intervention?	Yes. Successful adherence to the intervention was defined as at least 80% of the VR arm participants successfully completing the VR modules at least once.	100% of participants completing the VR at least once. Six (40%) completed the VR modules more than once.
7. Was the intervention acceptable to the participants?	Participants were keen to engage with the VR intervention. Acceptability was measured by refusal to engage with the VR modules.	All participants engaged with the VR at least once, and 40% engaged with it more frequently.
8. Was it possible to calculate intervention costs and duration?	An economic evaluation was not conducted.	–
9. Were outcome assessments completed?	Reasons for missing outcome assessments were participant withdrawal ($n = 1$).	29 (96.7%) of participants had complete outcome assessments.
10. Were outcomes measured those that were the most appropriate outcomes?	All outcomes were deemed valid and appropriate.	Participant-completed forms were largely complete (missing data points in three instances).
11. Was retention to the study good?	Successful retention in the study was defined by less than 10% attrition rate.	29 (96.7%) participants were successfully retained throughout the trial.
12. Were the logistics of running a multi-centre trial assessed?	No. This was a single-centre feasibility trial.	–
13. Did all components of the protocol work together?	The components of the trial and the intervention itself worked in this feasibility study.	Adherence to the intervention and study processes met the pre-determined criteria and show feasibility of progressing to full RCT if needed.
14. Did the feasibility/pilot study allow a sample size calculation for the main trial?	No. A sample size for a future full RCT was not calculated from the data in this study.	While our study suggests trends, meaningful effect size estimates are not possible given inherent imprecision of the data at small sample sizes.

Table 3. Outcomes from practical skills (OSATS) and knowledge (MCQ) acquisition assessments

Variable	All participants	VR group mean	Non-VR group
OSATS (mean ± SD)	28.1 ± 6.3	29 ± 6.0	27.3 ± 6.7
MCQs (mean ± SD)	15.5 ± 3.0	16 ± 2.8	15 ± 3.3

groups without self-reporting, and future studies may benefit from the inclusion of a more sophisticated method to detect contamination, such as unique user logins to track device use. It was noted that the VR group has only an 80% compliance rate with the pre-course booklet, and this could be because this group felt that they gained pre-learning adequately from the VR alone. Future studies should explore whether using VR results in neglect of other learning materials. However, different learners may benefit from different materials depending on whether they are a visual, auditory or practical learner. A further limitation is the relatively modest adoption of smartphone technology, the potential reliance on internet connection, and the not insignificant cost of this along with the VR headsets and software applications, which may limit the use of VR in some settings. Finally, the module was filmed in a high-income country setting which may limit the relevance to low-resource settings. The aim of the content was to demonstrate core anatomy and operative steps which should be transferrable to many settings. However, future studies should endeavour to create VR content from LMIC settings themselves.

This present study raises important considerations for surgical training in LMICs and globally. As smartphone technology use and internet access continue to increase, there is a real opportunity to leverage this technology for surgical training. Whilst immersive technology is unlikely to replace surgical mentorship, it has potential to enhance the limited training available globally and could shorten the length of training. Other evidence supports our preliminary findings that engagement in learning experience, and therefore experiential knowledge acquisition, is increased when an immersive modality (such as VR) is used.[27,28]

This IDEAL Stage 2b study was designed to assess whether VR was a worthwhile target for future investigation and investment as a technology solution for training. Using VR in LMICs is feasible and acceptable for surgical training, and VR should form part of the solution to address the lack of a trained global surgical workforce.

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Conflict of interest

All authors declare: no support from any organisation for the submitted work; no financial relationships with any organisations that might have an interest in the submitted work in the previous three years.

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Appendix 1. Engagement in learning and perceived meeting of learning objectives throughout the trial

Statement	VR group: percentage selecting each response					Non-VR group: percentage selecting each response				
	Strongly agree	Agree	Neutral	Disagree	Strongly disagree	Strongly agree	Agree	Neutral	Disagree	Strongly disagree
Perceived meeting of learning objectives										
1. I understand the indications for lower limb amputations (LLA)	86%	7.10%	7.10%	7.10%	0%	60%	40%	0%	0%	0%
2. I understand the pre-operative optimisation of LLA patients	92.90%	7.10%	0%	0%	0%	53.30%	40%	6.70%	0%	0%
3. I understand the anaesthetic considerations of LLA	71.40%	28.60%	0%	0%	0%	26.70%	46.70%	20%	6.70%	0%
4. I understand the use of prosthetics/orthotics	50%	50%	0%	0%	0%	21%	71.40%	7.10%	0%	0%
5. I understand the skin marking and incisions required for a BKA	85.70%	14.30%	0%	0%	0%	86.70%	6.70%	6.70%	0%	0%
6. I understand the skin marking and incisions required for an AKA	92.90%	0%	7.10%	0%	0%	86.70%	6.70%	6.70%	0%	0%
7. I can identify the neurovascular anatomy during a BKA	50%	35.70%	14.30%	0%	0%	46.70%	40.00%	13.30%	0%	0%
8. I can identify the neurovascular anatomy during an AKA	57.10%	28.60%	14.30%	0%	0%	46.70%	46.70%	6.70%	0%	0%
9. I can ligate vessels and nerves correctly	85.70%	7.10%	7.10%	0%	0%	46.70%	46.70%	6.70%	0%	0%
10. I can divide and shape the tibia and fibula during BKA	85.70%	7.10%	7.10%	0%	0%	53.30%	33.30%	13.30%	0%	0%
11. I can divide and shape the femur during AKA	85.70%	7.10%	7.10%	0%	0%	60.00%	26.70%	13.30%	0%	0%
12. I understand how to create skin flaps and close for BKA	78.60%	21.40%	0%	0%	0%	57.10%	35.70%	7.10%	0%	0%
13. I understand how to create skin flaps and close for AKA	78.60%	21.40%	0%	0%	0%	57.10%	35.70%	7.10%	0%	0%
14. I understand how to manage post-operative complications	78.60%	21.40%	0%	0%	0%	35.70%	57.10%	7.10%	0%	0%
15. Overall, I feel more confident performing LLAs now	71.40%	21.40%	0%	7.10%	0%	57.10%	35.70%	7.10%	0%	0%
Feedback on the hands-on course										
Learning										
1. I felt I learned new things during the course	100%	0%	0%	0%	0%	85.70%	14.30%	0%	0%	0%
2. I learned skills that will be useful to my clinical practice	100%	0%	0%	0%	0%	85.70%	14.30%	0%	0%	0%
3. The lectures helped me learn	92.90%	7.10%	0%	0%	0%	85.70%	14.30%	0%	0%	0%
4. The practical sessions helped me learn	100%	0%	0%	0%	0%	92.90%	7.10%	0%	0%	0%
5. The group discussions were useful for my learning	71.40%	28.60%	0%	0%	0%	86.70%	14.30%	0%	0%	0%
Design										
6. The lectures were well designed	42.90%	50.00%	7.10%	0%	0%	57.10%	42.90%	0%	0%	0%
7. The practical sessions were well designed	78.60%	14.30%	7.10%	0%	0%	78.60%	21.40%	0%	0%	0%
8. I had enough time to learn on the course	42.90%	42.90%	14.30%	0%	0%	21.40%	42.90%	21.40%	14.30%	0%
9. The overall structure of the course was well designed	50.00%	42.90%	7.10%	0%	0%	57.10%	35.70%	7.10%	0%	0%
Engagement										
10. I found the course enjoyable	85.70%	14.30%	0%	0%	0%	53.30%	40.00%	6.70%	0%	0%
11. I attended every session	100%	0%	0%	0%	0%	66.70%	20.00%	13.30%	0%	0%
12. I would recommend the course to colleagues	71.40%	28.60%	0%	0%	0%	80.00%	13.30%	6.70%	0%	0%
13. I found attending the course easy	71.40%	28.60%	0%	0%	0%	26.70%	53.30%	13.30%	0%	0%
14. The course met my expectations	78.60%	21.40%	0%	0%	0%	46.70%	40.00%	13.30%	0%	0%
15. I have gotten a lot out of attending this course	85.70%	7.10%	7.10%	0%	0%	73.30%	26.70%	0%	0%	0%
Feedback on the pre-course learning tools										
Learning										
1. Working with the learning object helped me learn	71.80%	28.60%	0%	0%	0%	40.00%	60.00%	0%	0%	0%
2. The written content from the learning object helped me learn	69.20%	30.80%	0%	0%	0%	33.30%	60.00%	6.70%	0%	0%
3. The graphics, animations and pictures from the learning object helped me learn	64.30%	35.70%	0%	0%	0%	13.30%	60.00%	26.70%	0%	0%
4. The learning object helped teach me a new concept	71.40%	28.60%	0%	0%	0%	26.70%	73.30%	0%	0%	0%
5. Overall, the learning object helped me learn	76.90%	23.10%	0%	0%	0%	42.90%	57.10%	0%	0%	0%
Design										
6. The learning tool was unnecessarily complex to use	0%	14.30%	21.40%	35.70%	28.60%	6.70%	6.70%	13.30%	46.70%	26.70%

(continued)

Statement	VR group: percentage selecting each response					Non-VR group: percentage selecting each response				
	Strongly agree	**Agree**	**Neutral**	**Disagree**	**Strongly disagree**	**Strongly agree**	**Agree**	**Neutral**	**Disagree**	**Strongly disagree**
7. The instructions and guidance in the learning object were easy to follow	57.10%	21.40%	21.40%	0%	0%	46.70%	40.00%	13.30%	0%	0%
8. The learning object was easy to use	50.00%	42.90%	7.10%	0%	0%	40%	53.30%	6.70%	0%	0%
9. The learning object was well organised	71.40%	28.60%	0%	0%	0%	46.70%	53.30%	0%	0%	0%
Engagement										
10. I liked the overall theme of the learning object	57.10%	42.90%	0%	0%	0%	46.70%	53.30%	0%	0%	0%
11. I found the learning object engaging	85.70%	7.10%	7.10%	0%	0%	33.30%	66.70%	0%	0%	0%
12. The learning object made learning fun	71.40%	28.60%	0%	0%	0%	35.70%	35.70%	28.60%	0%	0%
13. I would like to use the learning object again	100%	0%	0%	0%	0%	40%	60.00%	0%	0%	0%
14. I was able to use the learning object whenever I wanted	46.20%	23.10%	7.70%	23.10%	0%	26.70%	66.70%	6.70%	0%	0%
15. I think the learning object is user friendly	92.90%	7.10%	0%	0%	0%	42.90%	50.00%	7.10%	0%	0%
Feedback on the flipped classroom design										
Learning										
1. I felt the learning I did before the course prepared me well for the course itself	50.00%	42.90%	0%	7.10%	0%	28.60%	50.00%	14.30%	7.10%	0%
2. I made the most of my learning before the course	35.70%	35.70%	7.10%	21.40%	0%	7.10%	57.10%	14.30%	21.40%	0%
3. I learned new things before the course	28.60%	35.70%	28.60%	0%	7.10%	14.30%	64.30%	14.30%	7.10%	0%
4. I revised existing knowledge before the course	35.70%	35.70%	7.10%	14.30%	7.10%	28.60%	21.40%	42.90%	7.10%	0%
5. Overall, doing learning before the course made me gain more knowledge during the course	50.00%	21.40%	14.30%	14.30%	0%	42.90%	42.90%	7.10%	7.10%	0%
Design										
6. I think learning before the course was useful	76.90%	7.70%	7.70%	7.70%	0%	57.10%	28.60%	14.30%	0%	0%
7. I had enough time to learn before the course	23.10%	38.50%	15.40%	7.70%	15.40%	21.40%	42.90%	21.40%	14.30%	0%
8. I had the right materials and resources to learn before the course	21.40%	21.40%	42.90%	14.30%	0%	42.90%	50.00%	7.10%	0%	0%
9. Doing pre-course learning improved my experience of the course itself	35.70%	28.60%	21.40%	14.30%	0%	42.90%	50.00%	7.10%	0%	0%
Engagement										
10. I liked the overall structure of learning before the course delivery	50.00%	21.40%	28.60%	0%	0%	64.30%	28.60%	7.10%	0%	0%
11. I found the pre-course learning engaging	50%	14.30%	35.70%	0%	0%	35.70%	57.10%	7.10%	0%	0%
12. I enjoy learning before courses	42.90%	42.90%	14.30%	0%	0%	50.00%	42.90%	0%	7.10%	0%
13. I would do pre-course learning for future courses	64.30%	35.70%	0%	0%	0%	92.90%	7.10%	0%	0%	0%
14. In the future, I will carry out my pre-course learning in the same way I did this time	42.90%	14.30%	28.60%	7.10%	7.10%	50.00%	28.60%	7.10%	0%	14.30%
15. I enjoy learning in my spare time	78.60%	0%	14.30%	0%	7.10%	57.10%	35.70%	7.10%	0%	0%

AKA: above-knee amputation; BKA: below-knee amputation; LLA: lower-limb amputation.