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AOA Critical Issues in Education

Comparing Skill Acquisition and Validity of Immersive Virtual Reality with Cadaver Laboratory Sessions in Training for Reverse Total Shoulder Arthroplasty

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Introduction: Immersive virtual reality (iVR) allows surgical trainees to practice skills without risking harm to patients or the need for cadaveric training resources. However, iVR has never been directly compared with cadaver training, the longtime gold standard for surgical skill training. We aimed to compare skill acquisition using cadaver laboratory and iVR training methods for augmented baseplate implantation during reverse total shoulder arthroplasty (rTSA).

Methods: In a randomized controlled trial, junior orthopaedic surgery residents were assigned to a 1-hour training with either iVR or a cadaveric laboratory session with shoulder specimens. Before training, all participants viewed an overview lecture and technique video demonstrating key steps of augmented baseplate implantation for rTSA. Participants were assessed by a blinded evaluator using validated competency checklists during cadaveric glenoid baseplate implantation. Continuous and categorial variables were analyzed using the 2-sample *t* test and Fisher exact test.

Results: Fourteen junior residents (3 incoming matched postgraduate year [PGY1], 6 PGY1s, 1 PGY2, and 4 PGY3s) were randomized to training with either iVR (n = 6) or cadaver laboratory (n = 8). There were no significant differences in demographic data, previous experience with rTSA, or previous use of iVR ($p > 0.05$). There were no significant difference in total Objective Structured Assessment of Technical Skill score (91.2% [15.2] vs. 93.25% [6.32], −0.1406 to 0.1823, $p = 0.763$), Global Rating Scale score (4.708 [0.459] vs. 4.609 [0.465], −0.647 to 0.450, $p = 0.699$), or time to completion (546 seconds [158] vs. 591 seconds [192], −176.3 to 266.8, $p = 0.655$) in cadaveric glenoid baseplate implantation. Average cost of iVR hardware and a 1-year software license was $4,900, and average cost of a single cadaver laboratory was $1,268.20 per resident.

Conclusions: Among junior orthopaedic residents, there is similar skill acquisition when training with either cadaver laboratory or iVR. Although additional research into this field is needed, iVR may provide an important and cost-effective tool in surgical education.

Clinical Relevance: Emerging simulation and iVR technology simulation in surgical training programs can increase access to effective and high-level surgical training across the globe and improve quality of care.

Disclosure: The **Disclosure of Potential Conflicts of Interest** forms are provided with the online version of the article (http://links.lww.com/JBJSOA/A519).

Introduction

In the current landscape of surgical training, resident and fellow education typically combines supervised surgery in the operating room with didactic lectures, watching technique videos or reading technique guides, sawbones models, cadaver dissection/skills laboratories, and surgical simulators with varying degrees of fidelity[1-5]. As a result of the coronavirus disease 2019 (COVID-19) pandemic, previous reductions in residency work hour limits, and a continued emphasis on patient safety, surgical trainees have had reduced opportunities to refine their skills in the operating room[6,7]. As such, there has been an increased focus on optimizing these other educational tools to ensure trainees are adequately prepared to practice independently. At this time, simulation using fresh-frozen cadaveric specimens serves as the gold standard of training tools because this better replicates the anatomy and tactile feedback of live surgery than other educational tools[2,4-7]. Cadaver sessions allow trainees to practice complex procedures without risk of harming patients and may be further used to assess senior residents on their level of readiness for independent practice[5,6]. However, there are significant costs and logistical considerations associated with the acquisition, storage, and disposal of cadaveric specimens that prevent their more frequent use during surgical training[4-6]. Additional limitations include risk of disease transmission, tissue degradation, limited ability to provide objective feedback, and need for dedicated laboratory space[2,4,7,8].

The development of immersive virtual reality (iVR) has provided an adjunct to more traditional surgical education methods. iVR uses a head-mounted display, delivering visual and auditory guidance in a 3-dimensional (3D), simulated operating room environment, whereas hand controllers provide additional haptic (touch) feedback[1]. Similar to cadaver sessions, VR allows trainees to practice complex surgical skills in a safe and controlled setting[1,9,10]. Furthermore, the portability and immediate availability of iVR devices may permit training programs to purchase several devices for trainees to borrow on a weekly basis and practice procedures in their own homes, particularly relevant as a result of social distancing measures and disruptions in training because of the COVID-19 pandemic[3,9]. Trainees who use surgical simulators have been shown to outperform those only use traditional learning tools[8,11-13], and academic organizations such as the American Academy of Orthopaedic Surgeons, American College of Surgeons, and Accreditation Council for Graduate Medical Education have recognized the benefits of virtual, augmented, and mixed reality devices in making up for reductions in case volume[7]. Unlike cadaver laboratories, iVR systems allow trainees to repeat steps until achieving mastery, provide objective feedback metrics for the procedure performed, and have significant cost-saving potential[7,9].

When determining the utility of new educational tools, it is important to consider the validity and transferability of skills from the training setting to live surgery. Because of the complexity of simulating open procedures, early simulation tools in orthopaedic surgery focused on acquisition of arthroscopic skills, showing cost-effectiveness, the ability to distinguish between training levels, and improved performance after training sessions[8,9,14,15]. However, iVR has now provided opportunities for trainees to work on open surgical skills that would normally require cadaveric specimens, numerous instrumentation trays, and laboratory space[1,2,6,9,10]. Recent studies have shown promising results for iVR in teaching hip and shoulder arthroplasty with transfer of skills to the physical world. Despite this, iVR has not yet been directly compared as a training tool to the gold standard of cadaver laboratory sessions. Thus, it is the authors' goal to conduct a randomized controlled trial among junior-level orthopaedic surgery residents comparing training for reverse total shoulder arthroplasty (rTSA) procedures with iVR as compared with cadaver laboratories. We believe that training with iVR will demonstrate noninferiority with the hope of broader adoption of this tool in orthopaedic surgery curricula.

Methods

Participant Recruitment, Baseline Knowledge, and Randomization

This study was a randomized controlled trial of junior orthopaedic surgery residents (postgraduate year [PGY] 1-3) from a single training program to determine the effectiveness of iVR compared with cadaver laboratory training in surgical skill acquisition for rTSA. Junior residents were selected as the target population because they have had limited previous exposure to shoulder arthroplasty and thus would be at a similar baseline with equal ability to learn from either the cadaver or iVR platforms. This study received approval from our institution's review board before enrollment of participants. A flow diagram is provided in Figure 1.

Before training intervention, all participants were provided with a brief lecture and video demonstrating surgical techniques to establish a foundational level of knowledge. This lecture was provided by an expert-level, shoulder/elbow fellowship-trained orthopaedic surgeon, focusing on topics of relevant shoulder anatomy, imaging, classification schemes, indications and contraindications for rTSA, surgical approaches, and preparation and implantation of the reverse shoulder replacement augmented baseplate (Zimmer Biomet Comprehensive Reverse Shoulder System). At the end of the lecture, participants watched a technique video showing key steps of the implantation of the reverse shoulder replacement augmented baseplate as performed by the senior author.

Participants were then asked to complete a brief survey of baseline demographic information and previous experience with rTSA and virtual reality/simulator devices. They also completed a written knowledge test to assess their baseline level of knowledge regarding the procedure.

After the foundational lecture and baseline assessment, study participants were randomized within their respective postgraduate training year into either the intervention (iVR training) or the control (cadaver laboratory training) groups using a computer-generated block randomization sequence. A list of 6 numbers (either “1” or “2” for cadaver or iVR training, respectively) was generated for each training year, and participants were assigned by order of arrival training modality. This ensured equivalent levels of training between the 2 study groups.

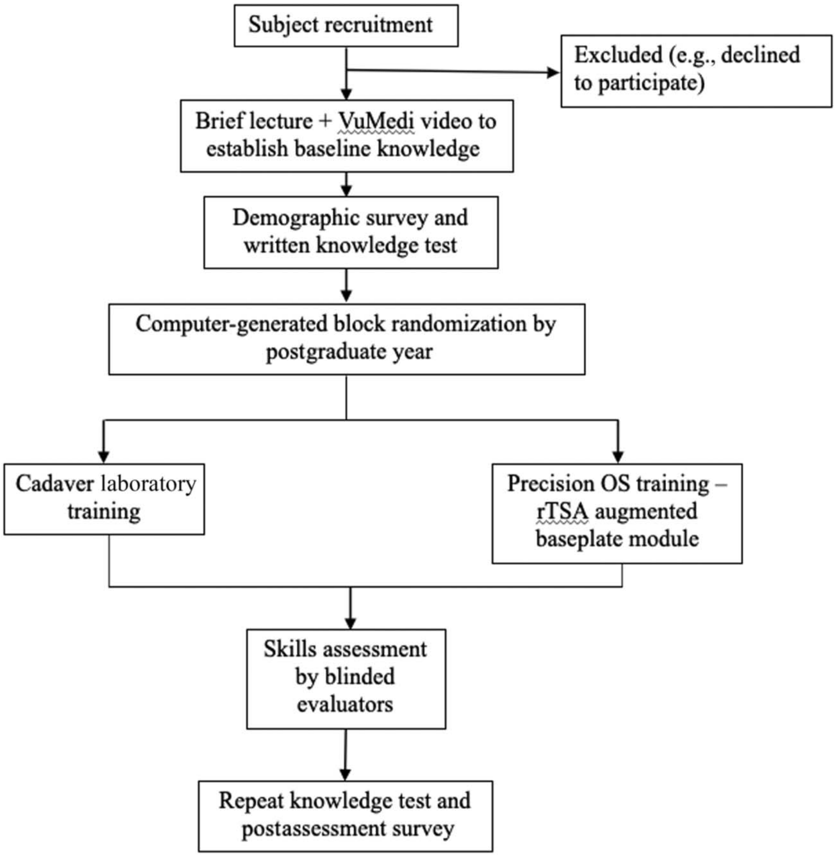

Fig. 1

Study flow diagram. rTSA = reverse total shoulder arthroplasty.

Initial Skills Training Session

After a brief safety demonstration from study personnel, participants in the intervention group used the iVR platform (PrecisionOS Technology). This system incorporates a head-mounted display with 3D visual and auditory cues to place the user in a virtual operating room; handheld controllers also provide haptic (simulated vibration and resistance) feedback and position tracking. Participants followed the curriculum within the system's Zimmer Biomet Comprehensive Augmented Baseplate module, allowing them to virtually perform the key steps in performing this portion of an rTSA. Participants were allowed to complete as many of the 9 available cases within the module as they wish within a 1-hour period of training time. At the end of the training session, the iVR system provides participants with objective metrics including Precision Score, feedback of bone reaming, and implant positioning. The Precision Score incorporates time to task completion with evidence-based parameters of performance (e.g., guide-pin insertion and glenoid baseplate orientation with respect to factors affecting implant longevity).

Each participant in the control group was be provided a fresh-frozen cadaveric shoulder specimen, as well as a printed copy of the lecture materials and a technique guide detailing steps of implantation of the augmented baseplate, and was allowed to perform the approach and exposure. Once the glenoid was been adequately exposed, study participants will be provided a 1-hour training period, during which they gained experience with the necessary surgical instruments, reviewed anatomical relationships, and practiced implanting the augmented baseplate.

Assessment of Skills

After the initial training sessions, study participants underwent formal evaluation of skill acquisition. As glenoid exposure was not considered as part of the skills assessment, each participant was provided with a preprepared fresh-frozen cadaveric shoulder specimen to standardize the approach and wear pattern (Favard E2). Participants were asked to demonstrate the key steps involved in implantation of the Comprehensive Augmented Baseplate and assessed using the Objective Structured Assessment of Technical Skill (OSATS) checklist and Global Rating Scale (GRS). The senior author, an expert-level, shoulder/elbow fellowship-trained orthopaedic surgeon (W.N.L.), was blinded to the results of randomization and the sole evaluator for the assessment session. The other senior, expert-level, shoulder/elbow fellowship-trained surgeon assisted in the initial overview lecture and cadaver laboratory training and was thus not blinded to the randomization results. The OSATS checklist (Appendix A) lists a series of 20 individual steps after glenoid exposure that are necessary to implant an augmented baseplate. Participants are scored as to whether they complete that step correctly or incorrectly. The GRS (Appendix B) assesses participants as to overall flow of the procedure and knowledge of steps, respect for tissues, and handling of instrumentation a Likert Scale from 1 to 5. Time to completion of the baseplate implantation was also recorded.

After assessment, participants were asked to complete a survey regarding the realism and utility of their assigned training tool and sentiments toward iVR in orthopaedic surgery education. Finally, they repeated repeat the written knowledge test to assess the change in level of knowledge after training.

Outcomes and Statistical Analysis

The primary outcome of this study was to compare performance after training with either iVR or cadaver laboratory sessions as reflected in OSATS, GRS, time to completion, and written knowledge scores. Secondary outcomes aimed to further validate iVR as noninferior to cadaver laboratory training through transfer of training, transfer-effectiveness ratio, and cost-effectiveness ratio measures.

TABLE I Demographic Characteristics

	Cadaver (n = 8)	iVR (n = 6)	95% Confidence Interval for Difference	p Value
Age (yrs), mean (SD)	28.25 (1.49)	27.5 (0.548)	−0.543 to 2.043	0.222
Sex, n				
Male	4	4	−0.345507 to 0.678840	0.627
Female	4	2		
PGY, n				
Incoming PGY1	2	1		
PGY1	3	3		
PGY2	1	0		
PGY3	2	2		
Dominant hand, n				
Right handed	6	6	−0.550057 to 0.0500570	0.473
Left handed	2	0		
Corrected vision, n				
Yes	3	3	−0.647114 to 0.397114	1.000
No	5	3		
Play video games? n				
Yes	3	3	−0.397114 to 0.647114	0.639
No	5	5		
Previous use of ZB comprehensive system, n				
Yes	2	2	−0.398653 to 0.565319	1.000
No	6	4		
No. of cases w/ZB comprehensive				
0 cases	6	6	−0.565319 to 0.398653	1.000
1-10 cases	2	2		
Previous use of simulators, n				
Yes	3	5	0.00948436 to 0.907182	0.138
No	5	1		
Previous use of VR, n				
Yes	3	1	−0.907182 to −0.00948436	0.138
No	5	5		
Use of VR in residency, n				
Yes	1	2	−0.233024 to 0.649691	0.538
No	7	4		
Previous use of technique videos, n				
Yes	7	6	−0.104172 to 0.354172	1.000
No	1	0		

iVR = immersive virtual reality, and PGY = postgraduate year.

To adequately power this study and detect a 25% difference in OSATS, 6 participants were needed in each group. Continuous variables were analyzed using the unpaired *t* test, whereas categorical variables were analyzed using the χ^2 test. Descriptive statistics are also reported below.

Results

Fourteen junior residents (3 incoming PGY1, 6 current PGY1, 1 PGY2, and 4 PGY3) were enrolled in this study and randomized to training with either iVR (n = 6) or cadaver laboratory training (n = 8). We held 3 training and assessment sessions over Spring 2022. We were unable to recruit equal numbers of residents in each postgraduate training year because of operating room schedules, vacations schedules, and limited laboratory availability. There were no statistically significant differences between the iVR or cadaver laboratory groups in regards to mean (SD) age (27.5 years [0.548] vs. 28.25 years [1.49], 95% confidence interval for difference in means −0.543 to 2.043, p = 0.22), sex (4 male/2 female vs. 4 male/4 female, −0.345507 to 0.678840, p = 0.627), dominant hand (6 right-handed [RH]/0 left-handed [LH] vs. 6 RH/2 LH, −0.550057 to 0.0500570, p = 0.473), use of corrective lenses (3 Y/3 N vs. 3 Y/5 N, −0.647114 to 0.397114, p = 1.000), previous use of the studied reverse shoulder system (2 Y/4 N vs. 2 Y/6 N, −0.398653 to 0.565319, p = 1.000)/number of cases performed using the system (2 w/0-10 cases vs. 2 w/0-10 cases, −0.565319 to 0.398653, p = 1.000), or previous use of simulators (5 Y/1 N vs. 3 Y/5 N, 0.00948436 to 0.907182, p = 0.138)/VR (1 Y/5 N vs. 1 Y/7 N, −0.907182 to −0.00948436, p = 0.138)/or technique videos (6 Y/0 N vs. 7 Y/1 N, −0.104172 to 0.354172, p = 1.000) as training adjuncts (Table I).

When comparing outcome measures between the iVR and cadaver training groups, we found no statistically significant difference in mean (SD) pretraining written knowledge score (60.7% [17.8] vs. 57.1% [21.4], −0.279 to 0.208, p = 0.750), OSATS score (91.2% [15.2] vs. 93.25% [6.32], −0.1406 to 0.1823, 0.763), GRS score (4.708 [0.459] vs. 4.609 [0.465], −0.647 to 0.450, p = 0.699), time to completion of assessment (546 seconds [158] vs. 591 seconds [192], −176.3 to 266.8, p = 0.655), nor post-training written knowledge score (58.3% [19.4] vs. 58.0% [13.5], −0.2160 to 0.2100, p = 0.975) (Table II).

Average cost of iVR hardware and a 1-year software license was $4,900; this can be shared among multiple users at a single training program and provides unlimited access to a variety of surgical modules. The average cost of a single cadaver laboratory training was $1,268.20 per resident (with the assumptions of the distributor's requirement of a minimum order of 10 shoulder specimens, each resident receives their own cadaver, and implants/instruments may be reused at least twice). Using the formulas shown in Figure 2, transfer of training was calculated to be 2.2% for mean OSATS scores and 2.1% for mean GRS, implying that both iVR and cadaver laboratory training are useful simulation tools. Transfer-effectiveness ratio was calculated to be 0.013, meaning 1 hour of VR training saves 1 minute of time to task completion compared with cadaver training. Using the cost values calculated above, cost-effectiveness ratio was 0.0032 for a single laboratory training session, and 0.34 under the assumption that VR is used biweekly (and associated cost averaged over 26 sessions), suggesting that VR shows increasing cost-effectiveness with repeated use.

Approximately 16.7% of iVR participants felt “definitely prepared” for the cadaver assessment session, whereas 50% felt “mostly” and 16.7% felt “somewhat prepared.” Approximately 66.7% of participants felt that the overall realism of iVR was “somewhat similar” to the cadaver laboratory. All participants in the iVR group felt that it was “very good” in its proficiency of teaching the steps of rTSA and responded “yes” when asked if they would use the technology again.

Discussion

The paradigms of surgical education have been largely unchanged for the past several centuries: Surgical resident and fellow education is largely obtained through supervised surgery in the operating room and complemented with additional learning tools and strategies. To the best of our knowledge, our study is the first to compare iVR training to cadaver training for surgical skill acquisition. Our blinded, randomized controlled trial demonstrated that junior orthopaedic surgery residents had no significant difference in skill acquisition when training with iVR compared with fresh-frozen cadaver methods. The 2 groups displayed similar knowledge of the technical steps of the procedure, handling of surgical instruments and soft tissues, and completed the procedure

TABLE II Comparison of Outcomes

	Cadaver (n = 8) Mean (SD)	iVR (n = 6) Mean (SD)	95% Confidence Interval for Difference	p Value
Pre-training written knowledge score (%)	57.1 (17.8)	60.7 (21.4)	−0.279 to 0.208	0.750
Total OSATS (%)	93.25 (6.32)	91.2 (15.2)	−0.1406 to 0.1823	0.763
Total GRS	4.609 (0.465)	4.708 (0.459)	−0.647 to 0.450	0.699
Time to completion (s)	591 (192)	546 (158)	−176.3 to 266.8	0.655
Post-training written knowledge score (%)	58.0 (13.5)	58.3 (19.4)	−0.2160 to 0.2100	0.975

GRS = Global Rating Scale, iVR = immersive virtual reality, and OSATS = Objective Structured Assessment of Technical Skill.

$$ToT = 100\% = \left(\frac{T_{cadaver} - T_{iVR}}{T_{cadaver}}\right) \qquad TER = \left(\frac{T_{cadaver} - T_{iVR}}{T_{iVR(initial\ training)}}\right) \qquad CER = \frac{TER}{\left(\frac{Cost\,(iVR)}{Cost\,(control)}\right)}$$

Fig. 2

Transfer of training (ToT), transfer-effectiveness ratio (TER), and cost-effectiveness ratio (CER) equations. iVR = immersive virtual reality.

in a similar timeframe. From the results of the iVR postassessment survey, most participants were satisfied with the realism of the iVR system, felt prepared for the final assessment session, and would plan to use the technology again.

Anecdotally, junior residents noted that "VR was most useful for learning the general steps of the procedure, [but] the tactile feedback of the device was lacking compared to getting the actual instruments in your hands." Similar to cadaver sessions, VR allows trainees to practice complex skills in a safe and controlled setting, but unlike cadaver laboratories, iVR allows trainees to repeat steps until achieving mastery, provides objective feedback metrics for the procedure performed, and has significant cost-saving potential. The results of our study may spark the development of additional training modules for other orthopaedic procedures, particularly those for which cadaveric specimens may be too costly or infeasible to obtain such as in cases of a specific, rare deformity.

Surgical simulation in surgical training programs has been shown to improve quality of care in low- and middle-income countries in general surgery trainees[16]. Emerging simulation and iVR technology can increase access to effective and high-level surgical training across the globe. The use of iVR in surgical training in low- and middle-income populations may aid in decreasing healthcare disparities that exist in developing countries.

This study has several limitations. This study had a relatively small sample size; however, our number of participants is similar to previous controlled trials comparing iVR training with non-VR training[17]. In addition, skill acquisition was evaluated using cadaveric specimens rather than real surgical scenarios. However, cadavers have been shown to be effective in demonstrating skill transfer validity in previous studies of cadaveric learning[18-20]. In addition, there is a potential for bias in a single expert surgeon evaluating trainee's performance, even when using validated assessments (OSATS). This could be improved by using multiple evaluators per participant. This study evaluated skill acquisition in junior learners and therefore may not be generalizable; further research should be performed to evaluate iVR training compared with cadaveric training in senior learners.

Conclusion

Training with iVR was effective in teaching implantation of an augmented reverse shoulder replacement skills to junior-level residents and was equivalent to the gold standard of traditional cadaveric training in this blinded, randomized controlled trial. This is the first known study directly comparing iVR surgical skill training with the gold standard of cadaver laboratory training. This study will hopefully lead to validation of iVR in broader orthopaedic skill training and adoption of iVR across orthopaedic surgery education.

Appendix

Supporting material provided by the authors is posted with the online version of this article as a data supplement at jbjs.org (http://links.lww.com/JBJSOA/A520 and http://links.lww.com/JBJSOA/A521). This content was not copyedited or verified by JBJS. ■

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