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Virtual Reality Simulation Facilitates Resident Training in Total Hip Arthroplasty: A Randomized Controlled Trial

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ABSTRACT

Background: No study has yet assessed the efficacy of virtual reality (VR) simulation for teaching orthopedic surgery residents. In this blinded, randomized, and controlled trial, we asked if the use of VR simulation improved postgraduate year (PGY)-1 orthopedic residents' performance in cadaver total hip arthroplasty and if the use of VR simulation had a preferentially beneficial effect on specific aspects of surgical skills or knowledge.
Methods: Fourteen PGY-1 orthopedic residents completed a written pretest and a single cadaver total hip arthroplasty (THA) to establish baseline levels of knowledge and surgical ability before 7 were randomized to VR-THA simulation. All participants then completed a second cadaver THA and retook the test to assess for score improvements. The primary outcomes were improvement in test and cadaver THA scores.
Results: There was no significant difference in the improvement in test scores between the VR and control groups ($P = .078$). In multivariate regression analysis, the VR cohort demonstrated a significant improvement in overall cadaver THA scores ($P = .048$). The VR cohort demonstrated greater improvement in each specific score category compared with the control group, but this trend was only statistically significant for technical performance ($P = .009$).
Conclusions: VR-simulation improves PGY-1 resident surgical skills but has no significant effect on medical knowledge. The most significant improvement was seen in technical skills. We anticipate that VR simulation will become an indispensable part of orthopedic surgical education, but further study is needed to determine how best to use VR simulation within a comprehensive curriculum.
Level of Evidence: Level 1.

It has been widely recognized that the traditional apprenticeship model of teaching may not sufficiently prepare current surgical trainees for clinical practice. This is especially true given pervasive concerns about patient safety, operating room (OR) efficiency, and resident work hour restrictions [1,2]. Surgical skills are not ideally acquired by observing and assisting alone [3,4], and as a result, the quality of trainee education may suffer.

In 2012, the American Board of Orthopedic Surgery and the Residency Review Committee for Orthopedic Surgery developed new training program recommendations [5,6] to standardize and improve residency curricula through use of quantifiable metrics and competency-based training. These recommendations identified simulation as a means by which OR training may be supplemented. The standardized training exercises were designed to prioritize affordable, low-tech options [7] such that complex procedures were simplified into focused, modular exercises. In response, many orthopedic residency programs have instituted "bootcamps" for their incoming residents, which the orthopedic

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and general surgery literature have shown to accelerate the acquisition of highly specific skillsets, improve the understanding of surgical instrumentation, and improve trainee confidence [2,8,9]. However, these modules fail to consolidate and reproduce the complex thought process and skills needed to perform a safe and expeditious surgery.

Virtual reality (VR) has emerged as a low-cost, highly accessible consumer product, and training on simulators has become standard in industries such as aviation. Combined with the continued rapid advancements in graphic processor technology and interest from software developers to create immersive surgical skill training simulations, VR users can practice surgical skills in an interactive and risk-free virtual environment. Other surgical disciplines, including general surgery, neurosurgery, and otolaryngology, have demonstrated positive results with the use of VR in resident training, as well as with preoperative planning [9–12].

Simulation in orthopedic surgery has focused primarily on arthroscopy [13], likely because of the procedural and instrumentational complexity involved with creating a realistic simulated open procedure, such as total joint arthroplasty. Advances in VR technology have also made simulation software more accessible and applicable to more complex procedures [14–16]. It is particularly attractive as a supplemental training method for total joint arthroplasty, as it obviates the need for lab space and multiple instrument trays.

To date, there has not been a study assessing the efficacy of VR simulation for learning operative arthroplasty skills. The objective of this study is to evaluate the utility of VR simulated total hip arthroplasty (THA) in providing targeted surgical training for orthopedic trainees. Specifically, the aim of this study was to compare the improvement in cadaver THA performance, specific aspects of surgical skills, and knowledge and perception of surgical anatomy and indications. We anticipate that VR simulation's life-like qualities will help connect the supplemental training directly to the surgical procedure, allowing earlier progress and proficiency in the operating room.

Methods

This study was a prospective randomized controlled trial and received approval from the Institutional Review Board before its initiation. Eligible study participants included all 14 incoming postgraduate year (PGY)-1 orthopedic surgery residents at our university academic medical center. Exclusion criteria included any PGY-1 resident unwilling to participate. One week prior to the planned baseline cadaveric THA surgery session, all eligible participants were invited to an information session regarding the study and were voluntarily enrolled. PGY-1 residents were specifically chosen for participation because they are surgically naïve and would be most likely to benefit from training focused on the procedural steps of THA.

Pretest

Immediately after enrollment, PGY-1 residents were asked to complete a multiple-choice pretest to quantify their baseline medical and procedural knowledge of hip arthritis and THA (Appendix 1). The pretest assessment form was developed with a specific focus on the pathophysiology of arthritis, surgical indications, anatomy, approaches, and radiographic imaging, as these are areas of interest in the Accreditation Council of Graduate Medical Education Orthopedic Surgery Milestones Report Worksheet for hip and knee arthritis (Appendix 2). All participants were unaware of this study prior to enrollment and were therefore unable to prepare for the pretest assessment, which allowed the test scores to be considered an accurate measure of baseline knowledge. No restrictions were imposed on participants during the 2 weeks between the pretest and the baseline cadaveric THA session; all trainees were allowed to prepare as much or as little for the cadaver session as they saw fit. During this 2-week period, trainees had not yet been randomized to the VR simulation group or the control group.

Cadaveric THA—Session 1

All 14 study participants performed a THA on a pelvis-to-toes cadaver specimen through a standard posterolateral approach at our institution's surgical simulation center to assess their baseline surgical skills. Establishing this score as a baseline allowed us to measure improvement in surgical ability, rather than raw score. The cadavers were positioned on peg boards and draped by senior orthopedic residents. Cadavers were specifically selected to exclude from use any specimens with prior hip fracture, prior hip surgery, inflammatory arthritis, morbid obesity > body mass index 40 kg/m^2, neuromuscular disease, and congenital abnormalities of proximal femur, acetabulum, or pelvis. Surgical instrumentation utilized in this study included the Synergy stem and R3 acetabular component (Smith & Nephew, Memphis, TN), Stryker (Mahwah, NJ) Series 7 sagittal saw, as well as our institution's standardized trays of THA instruments. These systems were chosen because they are most commonly used at our institution.

Study participants were designated as the primary surgeon for each cadaveric THA surgery. A PGY-4 or PGY-5 orthopedic resident pursuing fellowship training in hip and knee arthroplasty served as first assist. Additional assistance was provided by medical students. First assists were instructed to guide study participants with prompting questions and intervene only if:

(1) study participants requested assistance to progress to the next step;
(2) study participants were unable to progress through the surgery; and
(3) study participants committed or were at risk to commit a critical error (Appendix 3) that would impede further surgical progress.

Surgical competency was evaluated using a novel checklist adapted from a combination of the "Patient Care" portion of the Accreditation Council of Graduate Medical Education Milestones curriculum for hip and knee arthritis [17], operative checklist from the University of Toronto "Complex Total Hip Arthroplasty Perioperative Checklist" [18], and part of the Royal Canadian College of Physicians and Surgeons' competency-based curriculum [19] (Appendix 4). Scoring of each step was based on the Ottawa Surgical Competency Operating Room Evaluation scale [20]. Global assessment questions also adapted from the Ottawa Surgical Competency Operating Room Evaluation were used to measure each participant's knowledge of specific procedural steps, technical performance, visuospatial skills, efficiency, and flow during the session. Scoring began from the moment study participants began planning surgical incision and ended after stability testing and leg length checks were complete. Checklist evaluations were completed by 4 high volume, fellowship-trained, hip and knee arthroplasty surgeons at our institution (W.B.M., W.J.L., R.S., and L.P.). All evaluators scored only one study participant at a time.

Randomization

Immediately after the first cadaveric session, participants were randomized to one of the two cohorts by a computerized random number generator: VR-THA + standard study materials (VR cohort) vs standard study materials (standard cohort) only. Participants were privately notified of their randomization by e-mail and were asked not to disclose their designated cohort with any other study participant or research personnel. Only 2 members of the research team (D.W. and J.E.F.) were aware of the cohort assignments during this study. They played no role in data analysis and were instructed to keep the other study personnel blinded to the identity of the participant group make-up. All participants were provided standardized THA study material consisting of a book chapter on primary THA [21], an article on THA templating [22], and an article on soft tissue balancing of the hip [23].

VR Surgical Simulation

Prior to the VR-THA, participants were asked to complete a REDCap (Nashville, TN) survey evaluating their previous experience with video games and VR technology. The survey also quantified their level of interest and anticipated utility of VR technology in surgical skills training (Appendix 5). All surveys were administered by the research staff to ensure blinding of the other study personnel, and VR-THA simulations were then performed using the ORamaVR (Heraklion, Crete, Greece) software platform and the Oculus Rift CV1 (Menlo Park, CA) headset and hand controllers. This VR software is commercially available, and costs range from $4000-$8000, depending on institutional licensing agreements[†]. The software version used in this study does not offer haptic feedback to users. Each participant completed 2 simulated THAs using the VR system. Metrics collected by the VR software from these sessions were total amount of time spent and time per trial THA.

Upon completion of the VR-THAs, participants completed a REDCap exit survey (Appendix 6), which focused on their interest in using VR simulations for surgical skills training, as well as assessing for potential negative consequences (eg, nausea, motion sickness, etc.).

Cadaveric THA—Session 2

All study participants returned to the surgical simulation center 2 weeks after the first cadaveric THA session. Cadaveric THAs were performed in an identical manner using new cadavers. Participants were also asked to complete a posttest exit exam that was identical to their pretest immediately after their cadaveric THA to assess whether their knowledge had increased since the previous session.

Power Analysis

As this is the first study of its kind, we did not have a well-established precedent from which to base power calculations. Using Lehr's formula, and assuming $\alpha = 0.05$, $\beta = 0.05$ (power = 95%), and an anticipated mean milestone score improvement of 0.5 ± 0.25, the required total sample size for this study is 12.

Statistical Analysis

The change in pretest and posttest scores between the VR and control cohorts was defined as a primary outcome. The change in first and second cadaver THA scores between the VR and control cohorts was also defined as a primary outcome. The changes in global assessment scores from the first and second cadaver THA sessions were defined as secondary outcomes.

[†] For more information on use and licensing of the ORamaVR software, please contact Eleftherios Tsiridis, M.D., at tsiridisehs@gmail.com.

Table 1
Difference in Quiz Scores by Group as Indicated by *T*-Tests, Mean (SD).

VR Group	Baseline Quiz	Exit Quiz	Score Difference	*P* Value
Total (n = 14)	9.1 (1.5)	11.6 (2.7)	2.4 (2.9)	.008
Control (n = 7)	9.7 (1.8)	12.0 (2.5)	2.3 (2.8)	.070
VR Group (n = 7)	8.6 (1.0)	11.1 (3.1)	2.6 (3.2)	.078

VR, virtual reality; SD, standard deviation.

The *T*-tests and Mann-Whitney *U* tests were conducted to assess whether there was a significant difference between exit and baseline quiz scores, first and second cadaver session scores, and among the specific aspects of the scoring tool global assessment (primary and secondary outcomes). Because the cadaver sessions were scored by 4 different surgeons, a multivariate linear regression analysis was conducted to account for grader variability. The methodologic quality of our study was assessed using the 22-point Consolidated Standards of Reporting Trials checklist [24].

Results

Fourteen PGY-1 residents were enrolled in the study and completed all activities without attrition. The mean age of participants was 28.3 years (range 25-33), and the participants consisted of 9 males and 5 females. The VR cohort demonstrated greater improvement on written quiz scores compared with the standard cohort; however, this finding was not statistically significant (P = .078) (Table 1).

Using our assessment tool, a perfect score was defined as 240, consisting of a procedural score of 220 and a global score of 20 and representing complete independence in every step of a THA. There were no significant differences identified between the two cohorts with respect to mean pretest and first cadaver session scores (Table 2), indicating that there were no baseline differences in knowledge or surgical skills between the cohorts. In simple linear regression analysis of the effect of VR training on the cadaver THA assessment scores, there were no significant differences identified (P = .386) (Table 3). Examination of the raw scores demonstrated a disparity in the strictness of scoring among the 4 graders. A multivariate regression analysis, controlling for the effect different graders may have on scoring, was conducted to assess the graders' impact on score differences. This analysis demonstrated that the VR cohort improved their scores by 18 points, which was significantly better than the improvement seen in the standard cohort (P = .048) (Table 4). When considering the global assessment aspect of the cadaver sessions in multivariate regression, the VR cohort demonstrated greater improvement in all score categories (procedural steps, technical performance, visuospatial skills, efficiency, and flow) compared with the standard cohort, but this trend was only statistically significant for technical performance (P = .009) (Table 5).

The seven participants who were randomized to VR training each answered questions on their familiarity with video games and VR and their opinion of the utility of VR for surgical training (Table 6). Three of 7 (42.9%) reported experience with video games, while only 1 participant reported regularly playing video games.

Table 2
Comparisons in Mean Pretest and First Cadaver Session Scores According to VR Cohort Randomization.

Tests	VR	Non-VR	*P* Value
Mean pretest score	8.57	9.71	.1654
Mean first cadaver session score	79.14	74.71	.5773

VR, virtual reality.

Table 3
Difference in Cadaver Session Scores by Group, as Indicated by *T*-Tests, Mean (SD).

VR Group	Session 1	Session 2	Difference	*P* Value
Total (n = 14)	76.9 (14.1)	91.9 (24.6)	14.9 (27.9)	.066
Control (n = 7)	74.7 (12.9)	93.3 (23.4)	18.6 (25.2)	.099
VR Group (n = 7)	79.1 (15.9)	90.4 (27.6)	11.3 (31.9)	.386

VR, virtual reality; SD, standard deviation.

The mean amount of time spent doing VR simulation was 40:49 minutes (range 27:29-50:33, ±7.56). All 7 participants felt VR would be at least “mildly helpful” in surgical training. The participants who reported familiarity with video games were not any more or less likely to perceive VR to be a helpful learning tool; one rated it “very helpful,” another rated it “helpful,” and the third rated it “mildly helpful,” indicating that familiarity with video games is not related to a positive perception of the usefulness of VR simulation. None of the participants reported any negative consequences such as nausea or motion sickness.

Discussion

Our study is the first to look at the utility of VR simulation for teaching THA to trainees, and our results indicate that it is worth developing as a tool for resident education. Our results indicate that use of VR-THA simulation in its current form is likely to help beginning trainees improve their surgical skills.

The participants’ technical performance, which encompasses efficient execution of steps, avoiding pitfalls, and respecting soft tissues, improved after VR training. These results are supported by the findings of a 2016 meta-analysis on the effectiveness of VR simulation for arthroscopy, which demonstrated a significant improvement in technical skills [13]. In our study, VR training did not have a significant effect on the participants’ medical and procedural knowledge of arthritis and THA, as evidenced by performance on the written quiz. This was expected, as the VR-THA simulation program does not prompt the user with any recall or comprehension questions.

Surgery is a technical and learned skill, and achieving expert level in surgery requires acquiring complex skills such as superior pattern recognition, use of forward and backward reasoning within a highly structured knowledge base, self-monitoring, and minimal distractibility [25]. If we consider about 75% of the important events in an operation to be related to decision-making and 25% to be related to dexterity [26], no simulation will replace the live OR as a place to learn judgment and finer technical points of an operation from a master surgeon. However, the OR may not be always the ideal place to learn surgical skills because of numerous distractions related to patient safety issues, time constraints, inconsistent teaching ability of the surgical mentor, or lack of opportunity to prepare because of other clinical duties [27]. Technical execution is necessary for successful completion of any operation, but perhaps mastering basic technical skills early on in a lower-risk setting allows trainees to focus on developing surgical judgment in the live OR setting.

Table 4
Simple Regression of Difference in Cadaver Session Scores by VR Training and Grader.

Variable	β Coefficient (95% CI)	*P* Value
VR training	−7.3 (−40.8, 26.2)	.644
Grader session 1		
W.J.L. (ref)	—	—
W.B.M	23.5 (−7.3, 54.3)	.122
Grader session 2		
L.P. (ref)	—	—
R.S.	−41.0 (−62.8, −19.2)	<.001

VR, virtual reality; CI, confidence interval.

Table 5
Multivariable Linear Regression of the Difference in Technical Performance Score of Session 2 From Session 1 Predicted by VR Training and Grader.

Variable	β Coefficient (95% CI)	*P* Value
VR training	0.84 (0.26, 1.41)	.009
Grader session 1		
W.J.L. (ref)	—	—
W.B.M.	1.36 (0.79, 1.94)	<.001
Grader session 2		
L.P. (ref)	—	—
R.S.	−1.41 (−1.87, −0.94)	<.001

VR, virtual reality; CI, confidence interval.

Multiple studies from the general surgery literature have shown that skills learned in VR simulation improve resident performance in the OR [7,28,29]. VR laparoscopic training has been used since the early 2000s, with studies showing comparable improvement in skills seen in trainees who use VR simulators compared with those using standard trainers [30]. A randomized study of trainee performance after use of VR trainers for laparoscopic cholecystectomy demonstrated significant improvement in OR skills following use of VR simulation [7].

Based on our results and several published studies assessing VR simulation for arthroscopy, we believe that VR simulation is beneficial to orthopedic surgery trainees learning THA, as it helps trainees become familiar with the three-dimensional anatomy and instrumentation used to perform the operation without the lab space and instrument trays required for traditional simulation. Compared to learning from a video, VR simulation provides a more active learning experience. Even without the capacity for haptic feedback, use of the software can teach movement efficiency and flow through the procedural steps, which will be beneficial in the OR environment. We envision it used best as an adjunct to self-study with traditional reading materials and live OR training.

This study also helped identify ways in which current VR simulation technology should be developed to effectively teach orthopedic residents. In its current iteration, the data collection capabilities of the VR simulation software are limited. We feel they could be expanded to provide more detailed feedback to trainees, such as amount of time taken per step. We anticipate that improvements in VR simulation software will present opportunities for increased procedural complexity, which will make it more applicable to more senior trainees and to attending surgeons. For example, it may be helpful to simulate periprosthetic fractures, revision hip arthroplasty, or hip dysplasia cases. Junior residents may benefit more from a simulated anatomy lab to allow them to focus on a particular aspect of the procedure to improve, such as exposure of the acetabulum, rather than trying to get through the entire procedure at once. Additionally, building decision-making questions into the software may help trainees learn more than procedural steps from the simulation.

One limitation of this study is the small sample size. Our study was sufficiently powered to achieve statistical significance, and the similar scores in the first quiz and cadaver THA session indicate that it is unlikely that trainees of greater native aptitude were grouped together after randomization. Additionally, our residency program has the largest class size in the nation, and at a single center, it would not be possible to get more participants of the same level in each cohort. For our initial analysis of the potential benefits of VR simulation, we felt it best to focus on residents at a single level of training because it would lessen the chance of results being obscured by disparate training in the OR.

Table 6
Participant Description of Video Game Familiarity and VR Experience and Perspective.

Participant	Gender	Prior Video Game Experience	Regularly Plays Video Games	Perception of Utility of VR Session on Surgical Development	Time Spent VR Training (mm:ss)
1	Female	Yes	No	Very helpful	42:26
2	Female	No	No	Helpful	50:33
3	Male	Yes	Yes	Helpful	27:29
4	Male	No	No	Very helpful	42:23
5	Female	No	No	Helpful	42:23
6	Female	Yes	No	Mildly helpful	38:36
7	Male	No	No	Mildly helpful	41:54
Total counts and mean time	4 (57.1%) Female 3 (42.9%) Male	3 (42.9%)	1 (14.3%)	2 (28.6%) Mildly helpful 3 (42.9%) Helpful 2 (28.6%) Very helpful	40:49

VR, virtual reality.

Another limitation was the variability among graders, which suggests that even though a significant difference in scores by group was detected, the underlying measures may be somewhat subjective. We made all possible attempts to make the grading process as rigorous as possible, using only validated scoring tools to build our score sheet [17–20]. Having multiple graders evaluate a resident's skill level is realistic, as all faculty members may not agree on a resident's level of surgical ability. Multivariate analysis was used to statistically account for these inconsistencies. Finally, the short amount of time spent doing VR simulation likely limited the magnitude of the effect on the VR cohort. A previous study of the efficacy of VR laparoscopy simulation for general surgery residents required trainees to do 10 trials, with each session lasting approximately 1 hour [7]. The short duration of training reflects the logistical and financial constraints associated with coordinating the timing of this study; the PGY-1 residents in our program complete a surgical skills "bootcamp" during their first month of residency, and all segments of this study—quizzes, cadaver sessions, VR simulation—had to be completed during this time. Ideally, we would have liked for the participants to do more VR simulation training and to have more time between the 2 cadaver sessions, but we feel that the time we were able to allot was sufficient to see an effect. Additionally, the observed beneficial effect of VR simulation, even after a short exposure, underscores the immense potential for use of this technology as a teaching tool for residents.

Conclusion

VR simulation will become a useful tool for improving surgical skills, especially as software platforms continue to improve. We continue to work toward a comprehensive curriculum, integrating written material, VR simulation, and live OR learning and to teach orthopedic residents the necessary technical and decision-making skills. We anticipate that VR simulation will become an indispensable part of the orthopedic surgical education and believe that this technology will train and inspire the next generation of hip arthroplasty surgeons.

Level of Evidence

Level I, Randomized Controlled Study.

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