

Development and evaluation of a virtual reality based total hip arthroplasty surgical training application

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Abstract

Introduction:

Total hip replacement surgery is one of the most challenging procedures in orthopedic surgery. Due to its high sensitivity and risk of infection, it usually limits the ability of operating room students to attend and observe the procedure directly, especially at lower levels. The use of emerging technologies such as virtual reality and 360-degree videos, by creating an immersive experience close to physical presence, offers a solution to overcome this educational challenge. This study aimed to develop and evaluate a virtual reality-based hip replacement training program on the learning of operating room students.

Methods

In this study, which was designed as a two-group quasi-experimental (control-intervention) study with an additive structure, in which both groups had a common educational base (online) and the intervention group additionally received VR training, 36 operating room students (20 in the 5th semester and 16 in the 7th semester) were equally divided into two control groups (18 receiving conventional online training) and intervention groups (18 receiving online training combined with virtual reality and 360-degree video training). The level of student learning was measured with researcher-made tests (pre-test and post-test). The data were also analyzed and reported using SPSS statistical analysis software.

Results

In the intervention group (online education + VR), post-test scores were significantly higher than pre-test scores (Wilcoxon, $p < 0.001$), while in the control group (online education only) no significant difference was observed ($p = 0.057$). Between-group comparison showed that the mean post-test scores of the intervention group (12.83 ± 3.47) were significantly higher than those of the control group (6.72 ± 3.18) (independent T-test, $T = 5.512$, $p < 0.001$, very large effect size $d = 1.89$). The rate of learning progress in the intervention group was also significantly higher than that of the control group (Mann-Whitney, $p = 0.004$).

Conclusion

Compared to conventional online training, the virtual reality-based total hip arthroplasty training program significantly improved the learning of operating room students with a large effect size. Based on these findings, the use of virtual reality can be recommended as an effective supplement to conventional training in the field of specialized surgical training for operating room students.

Introduction

The spread of the information age, especially after the COVID-19 pandemic, has brought about significant changes in the methods of medical education (1). The introduction of technologies such as virtual and augmented reality, by enriching the content through dynamic images and interactive interfaces, has created more efficient and attractive learning environments (2, 3). Virtual reality, as defined by Burt (2017), is a hybrid environment of the real and virtual worlds that enables dynamic and realistic observation of imaginary objects (4), and has become one of the most effective tools for teaching advanced medical skills due to its ability to simulate accurate, safe, and user-friendly environments (5–9). Among the various methods for producing virtual reality environments, 360-degree videos have gained a prominent place in the field of education due to the lower cost and time spent in the production process. These videos have had a significant impact on increasing empathy, fostering reflective thinking, and improving skill-based learning (6, 10–12). Of course, the amount of learning that can be achieved with this technology depends on the user's level of immersion; using a headset and controller creates a more complete immersion and learning experience than viewing the same content on a phone or computer screen (13, 14). The field of operating room technology, due to its specialized nature, requires strong theoretical and practical training, but the operating room environment often does not provide an optimal learning environment due to patient safety considerations, time constraints, trainee density, and limited access to a good view of the surgical site (9). Virtual reality-based education eliminates location dependency and creates a realistic environment with the help of special headsets and immersive images, improving context-based learning and better transfer of skills (15, 16). Hip replacement surgery is one of the most complex and sensitive surgeries in orthopedics, and learning is rarely possible due to the high risk of infection and poor visibility of the surgical site despite the large number of students and residents in the operating room. Virtual reality simulations and 360-degree videos of surgeries are a complementary method to conventional training for better learning (17). Evidence suggests that skills learned in simulated environments transfer significantly to real-world clinical situations (18), and these environments provide a safe environment for repeated practice and enhance students' knowledge and skills in hip replacement surgery (5, 19). The close connection between theory and practice in education highlights the need for a deep understanding of learning theories. Based on the "situated learning" approach, acquiring knowledge in a context close to the real environment of its application is more effective. By creating virtual reality experiences, 360-degree video technology enables learners to apply their skills in simulated environments and understand concepts more deeply (11).

Given the significant advances in educational technologies and the challenges in learning orthopedic surgical techniques, especially femoral joint replacement surgery, which is not possible for students, especially at lower levels, to be present in the operating room due to the high risk of infection, the use of emerging technologies such as virtual reality and 360-degree videos as effective educational tools seems necessary and inevitable to familiarize students with the operating room and create an experience close to physical presence in the surgical environment. This study aims to develop and evaluate a virtual reality-based femoral joint replacement surgery training program with 360-degree videos on the learning process of students. Our research question for this study is: Does adding VR-based training with 360-degree videos to conventional online training increase the learning of operating room students compared to conventional training alone?

Methods

This study was designed as a two-group quasi-experimental (control-intervention) study with an additive structure, in which both groups had a common educational background (online) and the intervention group additionally received VR training.

The study sampling was conducted through convenience sampling and non-randomly; the reason for this selection was the limitations caused by war conditions in the access and presence of students at the university during the study period. However, the calculation of post-hoc statistical power, using G-Power software, for an independent T-test with an observed effect size ($d = 1.89$) and a sample size of 18 people in each group, showed a statistical power of 99.9%, which confirmed the adequacy of the sample to identify this large difference between the groups.

36 eligible students (20 in semester 5 and 16 in semester 7) participated in the study. First, all participating students received conventional online education; then, a subset of 18 students (9 students from each semester) who were able to attend the university due to their proximity to their place of residence, were divided into groups of 4–5 students at the designated time, and received additional virtual reality-based education in addition to online education (intervention group). Due to the lack of randomization, the homogeneity of the two groups in terms of background variables and pre-test scores was statistically examined and confirmed.

Description of the research sample

Due to the war conditions in the country and the inability of other students to attend at the scheduled time, this study was conducted as a convenience sample of students who were natives of Mashhad and were able to attend the university at the scheduled time. Information and coordination for students' participation and attendance in the study were provided by representatives of each class from the operating room technology department of Mashhad University of Medical Sciences. The present study did not have any financial benefits for the participants. A total of 36 operating room students (20 students from the 5th semester and 16 students from the 7th semester) participated, who were equally divided into two control groups (18 students, conventional online education) and intervention (18 students, online education combined with virtual reality-based education). The mean age of the sample was 22.64 years (standard deviation = 0.83; range 22 to 26 years). Among the participants, 20 (55.6%) were female and 16 (44.4%) were male, and the gender distribution was the same in the two groups. Only 5 people (13.9%) had previous experience using virtual reality technology. The Mann-Whitney test confirmed the homogeneity of the two groups in pre-test scores ($U = 135.000$, $z = -0.872$, $p = 0.383$).

Criteria for entering students into the study:

1. Students must have full consent to participate in the study.
2. They must have successfully completed the theory unit of orthopedic surgical technique.
3. They must be students in the 5th and 7th semesters of the operating room program.

Criteria for students to leave the study:

1. Individuals present in the study are unwilling to continue cooperation at any stage for any reason.
2. The student must not participate in the learning assessment test.

Research Design

This study is a two-group, two-stage (pre-test and post-test) quasi-experimental study with an additive within group design using a convenience sampling method, which was implemented in two stages:

- Stage 1 (Development): Design and construction of 360-degree video-based educational content for teaching total hip arthroplasty (THA) surgery to operating room technology students.
- Stage 2 (Evaluation): Measuring the level of student learning, by measuring the added effect of virtual reality-based education with 360-degree video in the intervention group to conventional education in the control-group. Figure 1. shows the overall flowchart of the study design.

Step 1. Design and development of the educational program

Section 1. Preparation of Educational Content

First, the content of educational materials related to femoral joint replacement surgery was extracted from reputable books used in the medical and undergraduate courses in the field of operating room technology by the researcher and was approved by the consulting professors in the project.

Then, the scenario for designing an application for training in virtual reality-based femoral joint replacement surgery was developed by the researcher and the project partner by reviewing articles in this field, and after approval by the consulting professors, it was handed over to a medical informatics specialist, and the work of producing the application with the existing scenario and content began.

In addition, the content prepared for preparing an educational PowerPoint on the topic of the aforementioned surgery was also used for conventional training.

Section 2. Production and Development of 360-Degree Videos

After obtaining permission from the university's educational vice chancellor, the researcher's letter of entry into the research environment in the operating room of Imam Reza (AS) Teaching Hospital was received, and after following up on the entry permit, the researcher entered the operating room of the aforementioned hospital. After the researcher entered the operating room, during the femoral joint replacement surgery, in coordination with the orthopedic specialist and the operating room manager, and by providing brief explanations to the personnel present in the operating room about the procedure, the 360-degree Insta camera was placed on the orthopedic specialist's head from the beginning of the surgery, and during the surgery, the specialist provided explanations about the desired operation.

It should be noted that in order to improve the quality of the recorded visual and video content of the surgical process, taking into account environmental considerations and operational limitations governing the operating room space, including the clarity of images and sounds, the aforementioned stage (which includes obtaining permission to enter the operating room and recording video images of the hip replacement surgery) has been carried out a total of three times until it was finally approved by the professors.

Finally, after preparing the final content of the hip replacement surgery, the researcher collected the videos and equipment. After categorizing and editing the desired content, the videos were provided to a specialist in the field of informatics for the development of the application and connecting the application operating system to the virtual reality headset.

To design the educational application for total hip arthroplasty surgery, the visual content of this surgery was used along with theoretical content taken from reliable sources in the field of orthopedics. After approval by a study team consisting of supervisors, consultants, and orthopedic specialists, and after necessary modifications were made, this content was compiled in the form of text, images, podcasts, questions, and 360-degree videos, and was finally implemented as an application to train operating room students and improve the quality of their learning.

Also, in order to prepare a PowerPoint for training the control group in the study, the content used in the application and images prepared in the aforementioned surgical position were used and approved by the operating room group professors.

First, based on studies and research articles conducted in the field of medical education based on virtual reality and 360-degree videos, effective factors in learning were extracted, including interactive learning, immersion, gamification, and adverse physical effects and complications. Then, the collected content was categorized and organized based on the indicators obtained from the conducted studies. Next, a set of 15 educational videos, compiled in a short-term (1–3 minute) schedule, was prepared and produced using the Insta 360-degree camera.

The videos prepared from the femoral joint replacement surgery, including: 1. Placing the patient in the appropriate position for the operation, 2. Prep and disinfect the surgical site, 3. Draping, 4. Setting up the surgical table and equipment, 5. Cutting the skin and subcutaneous tissue, 6. Cutting the fascia and muscles, 7. Accessing the damaged joint for prosthesis placement, 8. Removing the damaged joint, 9. Preparing the acetabulum cavity, 10. Placing the acetabular component, 11. Placing the acetabular liner, 12. Preparing the stem placement site, 13. Placing the stem, 14. Placing the head, 15. Closing the surgical site and dressing, were collected in a 1–3 minute format.

The equipment required for editing and displaying the video included a powerful computer, including an 11th-generation Intel Core i7 processor and NVIDIA GeForce RTX 3070 graphics card; Insta 360° camera; Adobe Premiere Pro, Unity Editor software. The equipment required to prepare the scenario for the educational video included an orthopedic operating room and a patient undergoing joint replacement surgery, a high-resolution graphics card to increase immersion, an HMD, and a surgical team consisting of an orthopedic surgeon, a surgical resident, a surgical assistant, and an operating room student.

After providing the required equipment and supplies, the position of the Insta 360 camera was determined for the most optimal quality and viewing angle (from the user's perspective and using the headset). The videos obtained from the user's perspective (from the student or professor's perspective) were evaluated by a team of experts, and the most optimal mode was selected. After completing the filming, the videos

were edited using Adobe Premiere Pro and GoPro Player software, and game-like interactions and the possibility of playing in virtual reality were achieved using the Unity software and engine. Also, at times during the video broadcast (with the approval of the team of experts), interactive questions were included, which participants had to answer correctly using the controllers, in order to be able to continue watching the video or enter the next stage. The videos were tested by research units before final use to eliminate possible problems.

In addition, the content of the videos was reviewed by an expert in the field of medical education for causing side effects in people, including dizziness, headache, and blurred vision during virtual reality-based training.

Step Two: Assessing the Effectiveness of the Training Program

In order to conduct the research, after obtaining permission from the Vice Chancellor for Education and the Director of the Operating Room Department, representatives of the two 5th and 7th semester classes of the operating room department were given a telephone call to explain the objectives of the research, how to conduct the research, the time of the exams, the time of the online class, and the time of the students' attendance to receive VR-based training. Given the limitations of attending the university at the appointed time, representatives of both classes were asked to inform their classmates, and students who met the study entry criteria were introduced and grouped.

The grouping of the participants in the study consisted of two groups:

The first group received surgical training through conventional training, online in the Skyroom software platform, using PowerPoint and lectures.

The second group, one week after receiving conventional training, received training in femoral joint replacement surgery using virtual reality and 360-degree videos of the aforementioned surgery.

The group participating in this study was a total of 36 students, 20 of whom were in the 5th semester and 16 in the 7th semester.

The control group in the study, which included all participating students ($n = 36$), after making the necessary coordination regarding the work process, was initially assessed with an online pre-test in two 45-minute sessions (one session for students in the 5th semester and one session for students in the 7th semester) in the first week of the study, to assess their knowledge about femoral joint replacement surgery.

Due to the limitations of university attendance during the war, the students' pre-test was conducted online 20 minutes before the start of the class by sending a link to the students' class group.

Immediately after the pre-test, an online training session on femoral joint replacement surgery was conducted in the Skyroom software at the accessible link that had been activated in advance through the university, for 45-minute using an educational PowerPoint and a lecture by the researcher.

The educational content for the training group consisted of lectures and PowerPoint presentations, with the researcher providing the necessary explanations about the surgery, in accordance with the source textbooks, along with images of the femoral joint replacement surgical position in the operating room, and participation in discussion, interaction, and questions and answers from students.

In the second week of the research process, the intervention group, which included 18 operating room students, 9 of whom were from semester 5 and 9 from semester 7, in small groups (4–5 people), during one week, with a coordinated schedule for 1 hour, went to the technology laboratory in the medical education department at the appointed time to receive training under the virtual reality-based femoral joint replacement educational application using 360-degree videos of the surgical environment, using the operating system and virtual reality headset, and received the desired training for 1 hour.

The educational content of the intervention group, based on virtual reality-based training, consisted of several 360-degree videos lasting 1 to 3 minutes, which were prepared from the position of a femoral joint replacement surgery performed in the operating room of Imam Reza Hospital. These videos were presented with explanations from an orthopedic surgeon and included gamification elements, including a question and answer session, scoring participants, and creating a competitive atmosphere among students.

The training process was as follows: after the students were initially familiarized with the virtual reality equipment, the researcher provided a brief explanation of how to work with the training application to each participant in the intervention group. Then, the training content was provided to the student step by step via a computer system. In this way, at each stage, first the explanations related to that part of the surgery were displayed, and then the corresponding 360-degree video was displayed. After watching the video, the student was given the opportunity to answer the questions in that section, and after answering and earning points, he was guided to the next stage of training. At the end of all training stages, the final score of each participant was visible in the form of a competition between students.

At the end of the third week from the start of the research, at a coordinated time, the post-test was made available to all students participating in the research via the test link for 20 minutes, and at the end of the test, the test answer sheet was also shown to the students.

Then, at the end of one month after the start of the study, all these students were evaluated at the scheduled time using an online post-test with 20 questions from the training conducted, and the scores received by the students were recorded and entered into the information form of each person. Also, the demographic and anthropological information of the students was recorded using a checklist.

The questions for the students' pre-test and post-test were designed based on the educational content used in both types of training and were examined to determine the validity and reliability of the study instrument.

It is worth noting that the questions related to the students' pre-test and post-test were equivalent.

Determining the Validity and Reliability of the Learning Assessment Tool

The assessment of the level of students' learning from the training of femoral joint replacement surgery was carried out with a researcher-made test from the relevant materials from reputable medical science books.

The researcher-made test questions to assess learning related to total hip arthroplasty surgery were designed in accordance with the lesson plan and steps of surgical training by collecting 20 four-choice questions under the supervision of the operating room professor and instructor, and then content psychometrics were conducted by obtaining opinions from the professors of the operating room training department of Mashhad University of Medical Sciences, who are experts in the field of orthopedics and educational design. The pre-test and post-test questions were equivalent. The scoring method was such that 1 point was given to each correct answer and 0 points were given for incorrect answers and no answer.

In order to determine the validity and reliability of the learning test questions, first the test related to femoral joint replacement surgery was designed in accordance with the lesson plan and steps of surgical training according to the opinions of the surgeon and the department instructor, and then content psychometrics were conducted by obtaining opinions from the professors of the relevant training department, who are experts in the field of orthopedics and educational design. To determine the validity of multiple-choice questions measuring the level of students' learning about total hip arthroplasty procedure (pre-test and post-test), a questionnaire with 20 four-choice questions was designed. The questions were given to 8 faculty members of the operating room group, and the face and content validity of the questions were examined using the content validity ratio (CVR) and content validity index (CVI). The calculated values for the content validity ratio (CVR) and the content validity index (CVI) were matched with the values of the Lawshe table, and all questions had appropriate validity. The reliability of the test measuring the level of students' learning about femoral joint replacement surgery was also calculated with a Cronbach's alpha coefficient of 0.897, which indicates that the designed test has internal consistency and appropriate reliability for research and statistical purposes. Table 1 presents the questions from the researcher-designed questionnaire used to assess the students' level of learning.

Table 1
Researcher-developed questionnaire for assessing learning levels

No.	Questions	A	B	C	D
1	What is the main indication for hip replacement surgery?	Developmental dysplasia of the hip	Proximal femoral bone tumor	Osteoarthritis*	Leg length discrepancy
2	For hip replacement surgery, which radiographic views are mandatory for the patient?	Distal femur	Lateral hip	AP *	Oblique hip
3	Which item is not considered part of the initial evaluation of a patient for hip replacement surgery?	Plain radiography (X-ray) of the involved joint	Checking the patient for absence of jewelry	Maintaining patient privacy	Specialized blood tests such as advanced coagulation tests*
4	Which of the following is used for positioning the patient in the lateral position?	Specialized blood tests such as advanced coagulation tests*	Headrest	Hand rest	Footrest
5	For femoral replacement surgery, what parts of the patient's body does the secondary prep include?	From the axilla to the knee	From below the ribs to the tip of the toes	From the iliac crest to the tip of the fingers*	Entire groin and perineal area
6	For draping a patient undergoing THA, which areas of the body must be completely covered and kept out of the surgical field?	Upper-posterior thigh	Greater trochanter prominence of the femur	Back and lateral pelvis	Upper half of the body, abdomen, and distal foot*
7	In THA via the direct lateral approach, where is the surgical incision located?	Circular incision around the greater trochanter	Linear incision at the lateral femur*	Curved incision at the center of the greater trochanter	Curved incision at the lower part of the greater trochanter
8	Based on the four-quadrant classification of the acetabulum (using horizontal and vertical lines passing through the ASIS), which area is considered the safest option for transacetabular screw placement?	Anterior-superior quadrant	Anterior-inferior quadrant	Posterior-inferior quadrant	Posterior-superior quadrant*
9	In femoral canal preparation, where should the correct entry point for the reamer be determined, and toward which anatomical structure should the reamer handle be directed during surgery?	Tip of the greater trochanter - directing the handle toward the posterior iliac spine	Center of the acetabular fossa - directing the handle toward the intertrochanteric line	Ischial tuberosity - directing the handle toward the knee	Piriformis fossa - directing the handle toward the greater trochanter*
10	Which of the following measures is correct regarding acetabular and tendon preparation during hip surgery?	To prevent injury to anterior and posterior vessels and nerves, direct instruments toward the outer (lateral) edge of the acetabulum.	During guidance of instruments such as drills and reamers, always maintain the direction of movement toward the medial border of the acetabulum so that vital anterior and posterior structures are not damaged.*	After labral incision, soft tissues are gathered into the acetabular fossa and dissected deep within the fossa and away from the edges.	To facilitate access, the gluteus maximus tendon is completely detached from its insertion and, after completion, reattached to the bone using a 1-cm cuff.
11	Which instrument is not used for THA surgery?	Cushing rongeur	Bone hook	Benett	Lowman bone clamp*
12	Which retractor is used in THA surgery?	Balfour	Weitlaner*	Richardson	Estman
13	What is the correct use of an osteotome?	To smooth raised bone edges or surfaces of large bones	To remove osteophytes beyond the bone boundary*	To keep bone fragments aligned in a fixed position	To retract different tissue volumes at different depths

No.	Questions	A	B	C	D
14	According to common principles in hip arthroplasty, which option is correct regarding acetabular implant sizing?	To achieve maximum inherent stability, an implant one size larger than the last reamer used should be used to create proper press-fit.	The final acetabular implant size is determined based on the diameter of the last reamer used, although using an implant the same size as the reamer may not provide sufficient inherent stability.*	Implant size is completely independent of reamer size and is determined solely based on patient anatomy and trial components.	All three options are correct.
15	In the process of acetabular preparation with power reamers, which method is correct?	Focus reamer guidance toward the posterior wall of the acetabulum to prevent excessive thinning of the anterior wall.	For faster work, rotate the reamer at maximum speed deep in the acetabulum to remove excess soft tissue as well.	Direct the reamer directly toward the medial wall of the acetabulum and start with the largest possible size.	Start the reamer with a size smaller than the final size and direct it downward (not toward the medial wall).*
16	To achieve final stability and correct alignment during femoral canal broaching, which action is essential?	Adjusting the neck cut before starting broaching	Removing axial pins before broaching	Placing the broach in axial stability within the canal*	Pushing the broach handle inward
17	In the process of broaching the femoral canal, to achieve final stability and correct alignment, which action is essential?	Pushing the broach handle inward (medially) and rapid hammering for deeper penetration	Directing the broach handle laterally and final placement of the broach in axial stability within the canal*	Adjusting the neck cut before starting broaching and using the largest broach at the very beginning	Removing axial pins before broaching and hammering with irregular blows
18	What is the criterion for complete seating of the stem in the femoral canal when striking with the hammer?	No advancement of the stem with hammer blows*	Sharp and high-pitched sound when striking	Advancement of the component at least 5 mm with each blow	Rebound of the component after each blow
19	After complete implant placement and hip reduction, before wound closure, what is the surgeon's final and primary assessment focused on?	Evaluating stability and range of motion*	Evaluating aesthetics and skin incision length	Final count of gauze and needles on the surgical table	Patellar function test
20	Which suture is suitable for closing muscles?	Vicryl 1*	Nylon 1	Ethibond	Vicryl 2/0

Data analysis:

First, the normality of the data distribution was examined with the Shapiro-Wilk test, and then other research analyses were performed.

The Wilcoxon test was used to determine and compare the average learning score of students in femoral joint replacement surgery training before and after the intervention, separately in the control and intervention groups. Also, the average learning score between the intervention and control groups was compared before the intervention with the Mann-Whitney test and after the intervention with the independent t-test. In order to determine the correlation between the pre- test and pos-test learning scores, separately in each of the two intervention and control groups, the Pearson correlation coefficient was calculated. Also, the average pre-test and post-test learning scores of students in the 5th and 7th semesters were compared with the independent t-test. To measure the level of satisfaction with the training in the intervention group, the one-sample t-test was used, and finally, the average changes before and after conventional training and virtual reality (VR) in both intervention and control groups were compared with the Mann-Whitney test.

Findings

A total of 36 operating room students (20 from semester 5 and 16 from semester 7) participated in this study, who were equally divided into two control groups (18, receiving conventional online education) and intervention (18, receiving online education combined with virtual reality-based education) (in fact, our goal is to measure the added effect of VR education compared to online education alone on student learning, and for this purpose, the participants' scores were examined in two pre-test and post-test phases).

The mean age of the total sample was 22.64 years (standard deviation = 0.83) with a range of 22 to 26 years.

In terms of gender, 20 (55.6%) were female and 16 (44.4%) were male, with the gender distribution in the two groups being the same (10 females and 8 males in each group). Only 5 (13.9%) of the participants had previous experience with virtual reality technology.

Demographic information of the participants and descriptive statistics of the study group are presented in Table 2.

Table 2
Absolute and relative frequency distribution of demographic variables of research samples

Variable	Category / Index	Total Sample(n = 36)	Semester 5(n = 20)	Semester 7(n = 16)	Control Group(N = 18)	Intervention Group(N = 18)
		Frequency (%)	Frequency (%)	Frequency (%)	Frequency (%)	Frequency (%)
Gender	Female	20 (55.6%)	9 (45%)	11 (68.8%)	50%	50%
	Male	16 (44.4%)	11 (55%)	5 (31.3%)		
Age	Mean $\pm$ SD	22.64 $\pm$ 0.83	22.20 $\pm$ 0.52	23.19 $\pm$ 0.83	22.44 $\pm$ 0.51	22.83 $\pm$ 1.04
	Range	22–26	22–24	22–26	(22–24 yrs)	(22–26 yrs)
Prior VR Experience	Yes	5 (13.9%)	5 (25%)	0 (0%)	0%	13.9%
	No	31 (86.1%)	15 (75%)	16 (100%)		
Academic Semester	Semester 5	20 (55.6%)				
	Semester 7	16 (44.4%)				
Total Sample		36 (100%)	20 (100%)	16 (100%)	36 (100%)	

Due to the non-normal distribution of the data (Shapiro-Wilk test), the non-parametric Wilcoxon test was used. In the control group, the difference between pre-test and post-test scores was not statistically significant ($z = -1.902$, $p = 0.057$, $r = 0.45$), which is consistent with the nature of this group (no intervention). In contrast, in the intervention group, 88.9% of participants (16 out of 18) experienced score improvement, and the mean post-test scores were significantly higher than the pre-test ($z = -3.492$, $p < 0.001$, $r = 0.82$), indicating a strong and positive effect of the intervention. Descriptive indices and results of intra-group tests (pre-test and post-test) are presented in Table 3.

Table 3
Descriptive indices and results of intra group tests (pre-test and post-test)

Group	Phase	Mean	Standard Deviation	Recovery Count / Rate	Wilcoxon Test	Effect Size (r)
Control	Pre-test	-	-	-	$z = -1.902$	0.45
Control	Post-test	-	-	-	$p = 0.057$	-
Intervention	Pre-test	-	-	16 (88.9%)	$z = -3.492$	0.82
Intervention	Post-test	-	-	-	$p < 0.001$	-

Independent t-test showed that the mean post-test scores in the intervention group (mean = 12.83; standard deviation = 3.468) were significantly higher than those in the control group (mean = 6.72; standard deviation = 3.177) ($t = 5.512$, $df = 34$, $p < 0.001$, $d = 1.89$), indicating a very large effect size.

Comparing the rate of progress (difference in scores) between the two groups with the Mann-Whitney test also showed that progress in the intervention group was significantly greater than that in the control group ($U = 75.500$, $z = -2.844$, $p = 0.004$, $r = 0.47$). Information regarding the comparison between groups of students in the post-test is presented in Table 4.

Table 4
Between group comparison in post-test and rate of progress

Variable	Intervention Group	Control Group	Statistical Test	Test Statistic	Degrees of Freedom	Significance Level (p-value)	Effect Size
Post-test Score	Mean = 12.83 SD = 3.468	Mean = 6.72 SD = 3.177	Independent t-test	$t = 5.512$	$df = 34$	$p < 0.001$	$d = 1.89$ (Very Large)
Improvement Rate (Difference)	-	-	Mann-Whitney	$U = 75.500$ $z = -2.844$	-	-	-

Pearson correlation coefficient showed that in the control group, there was a positive and significant correlation between pre-test and post-test scores ($r = 0.613$, $p = 0.007$), while in the intervention group this correlation was not significant ($r = 0.018$, $p = 0.944$). This finding suggests that the educational intervention eliminated the natural relationship between basic knowledge and final performance and had a uniform effect on students with different knowledge levels. Information regarding the correlation of students' pre-test and post-test scores is presented in Table 5.

Table 5
Correlation between pre-test and post-test scores in each group

Group	Correlation Coefficient (r)	Significance Level (p)	Interpretation
Control	+0.613	0.007	Positive and significant correlation (preservation of initial ranking)
Intervention	+0.018	0.944	No significant correlation (loss of relationship between baseline knowledge and final performance)

Regarding the comparison between academic semesters of students, the Mann-Whitney test results indicated homogeneity of students in semesters 5 and 7 in the pre-test ($U = 107.000$, $z = -1.728$, $p = 0.084$). Although both groups showed significant improvement after the intervention (semester 5: $z = -1.9$, $p < 0.001$, $r = 0.42$; semester 7: $z = -3.4$, $p < 0.001$, $r = 0.85$), no significant difference was observed in post-test scores ($U = 137.00$, $p = 0.462$) or progress rate ($U = 139.000$, $p = 0.498$) between the two semesters; therefore, the effectiveness of the intervention was similar in both semesters. Table 6 shows the comparison of the effectiveness of the intervention based on the students' academic semester.

Table 6
Comparison of intervention effectiveness based on academic semester

Variable	5th Semester Group	7th Semester Group	Mann-Whitney Test	Test Statistic	Significance Level (p)	Effect Size (r)
Pre-test (Baseline Homogeneity)	-	-	Mann-Whitney	$U = 107.000$ $z = -1.728$	$p = 0.084$	-
Post-test	Significant improvement $z = -1.9$, $p < 0.001$, $r = 0.42$	Significant improvement $z = -3.4$, $p < 0.001$, $r = 0.85$	Mann-Whitney	$U = 137.000$	$p = 0.462$	-
Improvement Rate	-	-	Mann-Whitney	$U = 139.000$	$p = 0.498$	-

Overall, in this study, the educational intervention had a strong effect on student learning ($p < 0.001$, $d = 1.89$), such that 89% of the intervention group improved, and this effect was independent of the initial baseline knowledge (the correlation between pre-test and post-test was eliminated in the intervention group). Also, the effectiveness of the intervention was observed equally in both academic semesters 5 and 7 ($p = 0.462$), and the control group did not show a significant change ($p = 0.057$). Overall, the intervention significantly improved learning with a large and uniform additive effect. Figure 3 shows the comparison of the mean learning scores in the pre-test and post-test in the two groups.

Discussion

This study aimed to develop and evaluate the applicability of a virtual reality (360-degree video)-based hip replacement surgery training program and determine its impact on learning in 36 students in the 5th and 7th semesters of the operating room program at Mashhad University of Medical Sciences. The main findings showed that adding virtual reality-based training to conventional online training significantly and with a very large effect size ($d = 1.89$) improved students' learning scores, while the control group (receiving conventional online training only) did not show a significant change in their scores.

The central finding of this study was the significant superiority of the intervention group over the control group in post-test scores ($T = 5.512$, $p < 0.001$, $d = 1.89$), such that 88.9% of students in the intervention group experienced an improvement in their scores. This finding is consistent with the results of the vast majority of previous studies. For example, Mansouri et al. reported significant improvements in learning in the training of the comatose patient, which is consistent with the present findings in the same field of study and with a similar intervention/control group design. Similarly, Chang et al. in obstetrics (20), Im et al. in dental radiology, and Tanaka et al. in neurosurgery all reported significant superiority of the 360-degree virtual reality group over conventional or 2D methods. The very large effect size obtained in the present study ($d = 1.89$) is also consistent with the findings of Katabi et al. in their systematic review, who reported improvements in performance at all skill levels from novice to experienced; however, in the present study, since all participants had no previous clinical experience in this specific surgery (similar to the novice population), the rate of improvement was expected to be high, which was confirmed.

In contrast, the findings of this study are inconsistent with the conclusion of Arents et al. that adding 360-degree video to a gentle cesarean section training program did not significantly improve long-term recall of knowledge. This difference can be explained by several factors: first, Arents et al.'s study measured long-term recall, while the learning assessment in the present study was conducted immediately after the intervention; second, the sample size and distribution of participants' prior experience in the two studies were different. This difference highlights the need for future studies with long-term follow-up in the present study. The relative stability of the control group scores ($z = -1.902$, $p = 0.057$) along with the homogeneity of the groups at pre-test ($U = 135.000$, $p = 0.383$) is methodologically important; this suggests that the improvement observed in the intervention group was not due to a repeated test effect or bias in the initial allocation of participants and could be specifically attributed to the virtual reality intervention. This pattern is consistent with the methodological design of studies such as Chan et al. and Im et al., in which the control group with conventional or 2D training also made more limited progress than the intervention group (16).

One of the interesting findings of this study was the loss of significant correlation between pre-test and post-test scores in the intervention group ($r = 0.018$, $p = 0.944$) compared to a significant positive correlation in the control group ($r = 0.613$, $p = 0.007$). This finding suggests that VR-based education had a relatively uniform effect on students' learning, regardless of their prior knowledge; in other words, this method can reduce the knowledge gap between students with different levels of initial preparation. This finding is consistent with the theoretical framework of experiential learning proposed in the review study by Maroukakis et al., which introduces experiential learning as the most compatible with virtual reality environments and emphasizes the role of this technology in providing a practical and uniform experience for all learners, regardless of their prior knowledge (20).

The results showed that although the intervention was significantly effective in both semester 5 ($z = -1.9$, $p < 0.001$) and semester 7 ($z = -3.4$, $p < 0.001$) groups, there was no significant difference in the rate of progress between the two semesters ($U = 139.000$, $p = 0.498$). This finding suggests that the effectiveness of 360-degree video-based education is not dependent on the academic level or the level of previous exposure of students to more specialized courses and can be used as a complementary educational tool for different levels of education in the operating room field; a result that is in line with the approach of Fukuta et al., who introduced 360-degree video as a generalizable tool for familiarizing students at different stages of education with the operating room environment (21).

Strengths of the study

1. Examining the effect of the intervention at two different academic levels (semesters 5 and 7), which helps generalize the findings across different levels of the curriculum.
2. The age group of the study participants is in the 22–26 age range, which reduces the possibility of bias in the type of perspective and learning style of the students.

Limitations of the study

1. Relatively limited sample size (36 students), which limits the generalizability of the findings; a limitation that is common to most similar studies in this field.
2. Conducting convenience sampling due to war conditions and the inability of some students to be present at the university at the scheduled time prevented a randomized study design.
3. Failure to measure long-term retention of learning, which limits the possibility of direct comparison with the finding of Arents et al. about the lack of improvement in long-term recall.
4. The use of 360-degree video as a semi-interactive medium (compared to fully interactive virtual reality environments such as the study by Koyachi et al.), which may have limited the level of immersion and overall interaction compared to fully interactive systems.

Suggestions for Future Studies

1. Multicenter studies with larger sample sizes should be conducted to increase the generalizability of the findings.
2. Follow-up studies should be designed to assess learning at longer time intervals (e.g., one to three months after the intervention) to assess the retention of knowledge.
3. The role of variables such as learning motivation, learning style, and cognitive load in the relationship between usability/satisfaction and learning performance should be investigated.
4. The effectiveness of semi-interactive 360-degree video versus fully interactive virtual reality environments (such as controller-based systems) in teaching surgical procedures should be compared.
5. The user interface of the system should be improved with the aim of increasing the SUS score above the international reference average.

Conclusions

The results of this study showed that adding 360-degree virtual reality video-based training to conventional online training significantly and with a very large effect size improved the learning of operating room students in the field of femoral joint replacement surgery, and this effect was uniform regardless of the students' educational level and initial knowledge level. Given the alignment of these findings with the majority of international research literature, the use of 360-degree videos is recommended as a complementary, low-cost, and scalable educational tool alongside conventional clinical training in the operating room field, especially for surgeries with limited clinical access, such as femoral joint replacement.

Abbreviations

VR
Virtual Reality
THA
Total Hip Arthroplasty
HMD
Head mounted Display

Declarations

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Data Access

The dataset used in this study can be obtained by contacting the corresponding author upon reasonable request.

Ethical Approval and Consent to Participate

This study is based on a master's thesis in the field of Educational Technology, which was approved by Mashhad University of Medical Sciences with the Code of Ethics in Research IR.MUMS.MEDICAL.REC.1404.309. All protocols conform to the ethical principles of the Declaration of Helsinki for Medical Research Involving Human Subjects, and the authors have confirmed this. None of the authors have financial or private relationships with any commercial, academic, or political organization or individual that could have influenced this study. Online informed consent was obtained from all participants involved in this study.

Consent for Publication

Not Applicable.

Conflict of Interest

The authors declare that they have no conflicts of interest.

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Figures

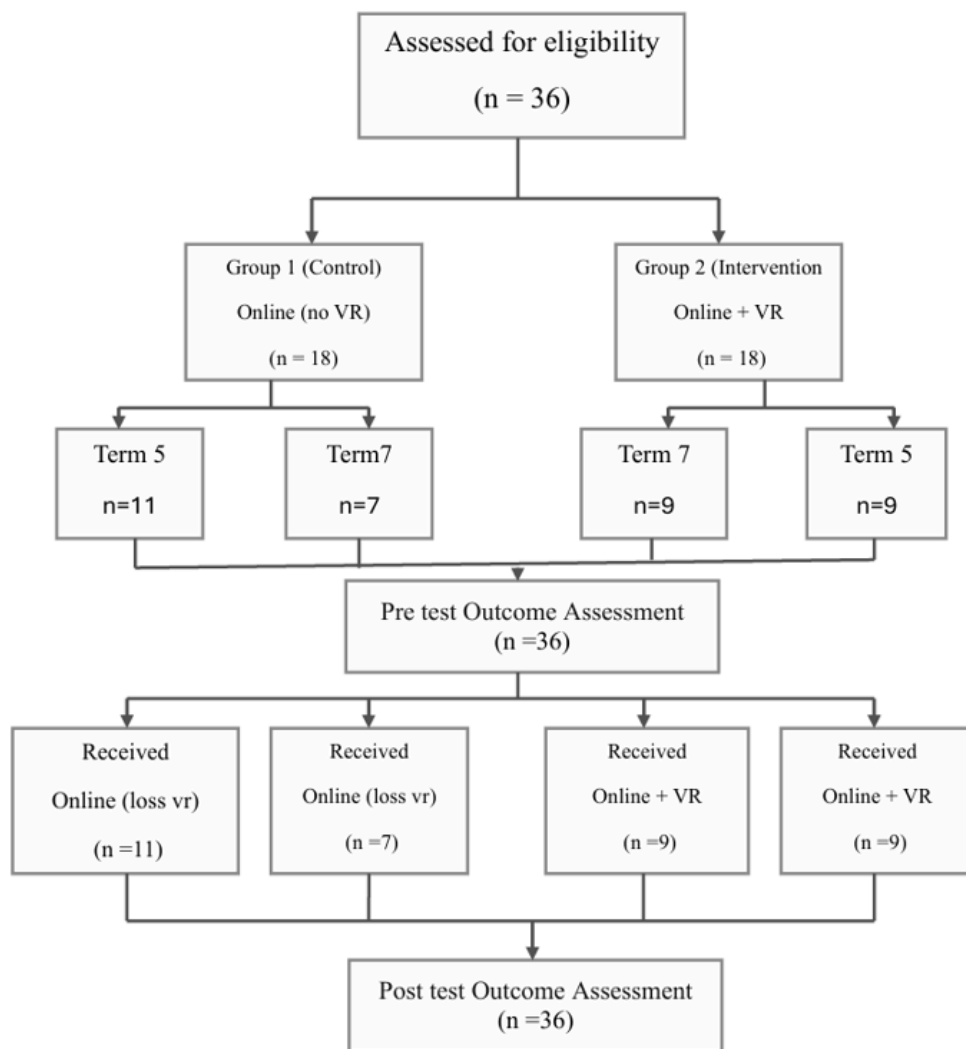


Figure 1

Flowchart of study



Figure 2

Snapshot from a 360-degree video recording using an Insta360 camera of a total hip arthroplasty procedure

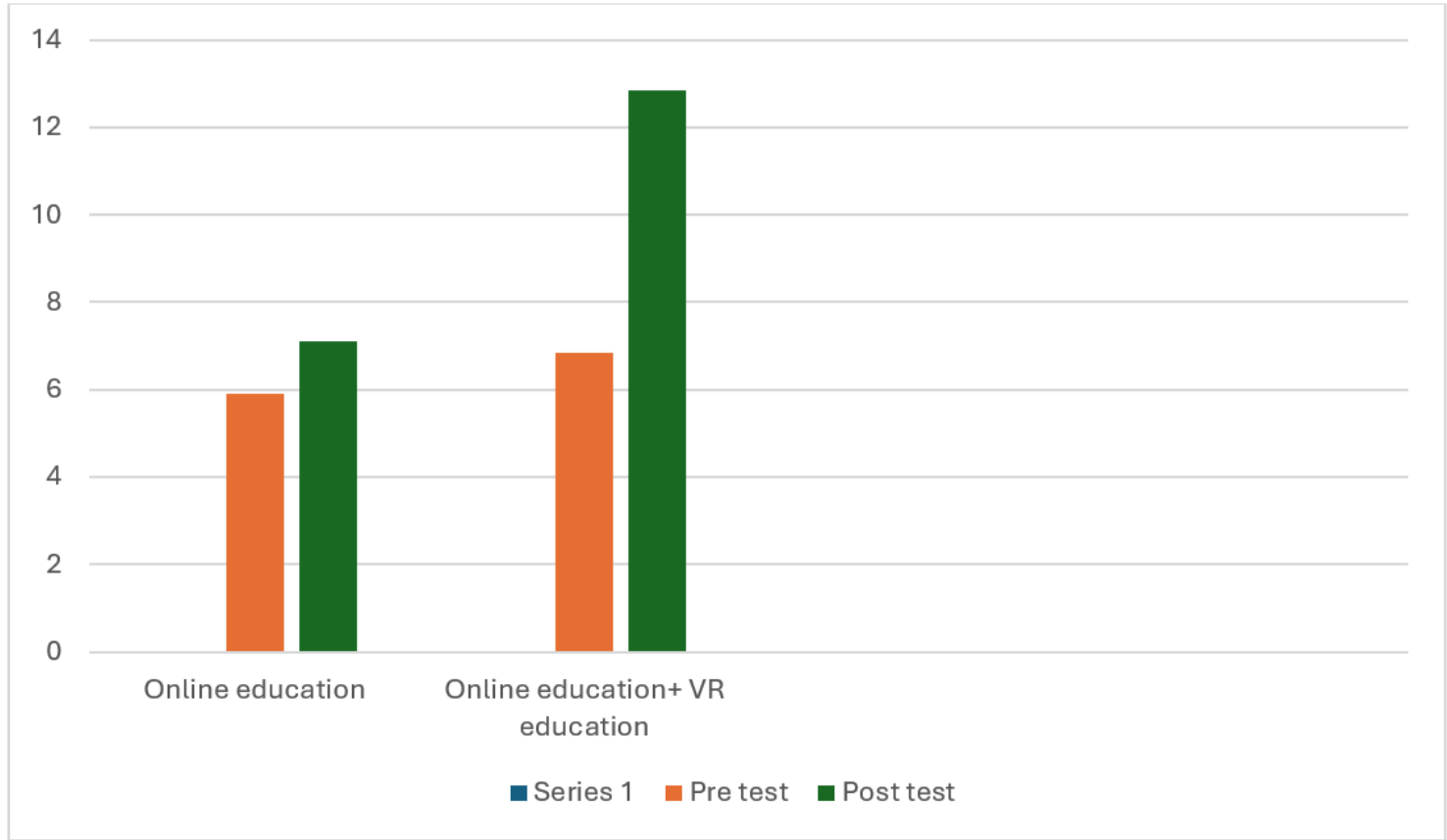


Figure 3

comparison of average learning scores in pre-test and post-test in two group

Supplementary Files

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