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Major Article

Virtual reality as a learning tool for improving infection control procedures

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Hand hygiene
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Objective structured clinical examination (OSCE)
Lecture
Compliance

A B S T R A C T

Background: Hand hygiene and donning personal protective equipment (PPE) are essential techniques for infection control; however, low compliance is an issue. The effectiveness of virtual reality (VR) in learning infection control procedures is unknown.
Methods: To verify the effectiveness of VR, medical students were categorized into VR or lecture groups (n=21 each). Each group was given the same curricular content; one group received the training through VR learning using a fully-immersive 360-degree video and the other was conventional lecture-style learning. Before and after the training, they were evaluated for the implementation of hand hygiene and PPE using an Objective Structured Clinical Examination method. Post-test questionnaires were administered.
Results: The scores for hand hygiene, donning PPE, and the total score increased after learning in both groups. There was no difference between the pre-test total scores of the two groups (7 [5-9] vs 6 [5-7.5], *P*=.352); however, the VR group had significantly higher post-test total scores than the lecture group (12 [9.5-12] vs 9 [8-12], *P*=.024). More students in the VR group responded that they enjoyed the training and would like to use the same learning method next time.
Conclusions: VR can be a useful tool for learning and practicing appropriate infection control procedures.
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BACKGROUND

Regular hand hygiene and wearing of personal protective equipment (PPE) are basic procedures to protect patients and health care providers from infection.[1,2] However, compliance is not high in actual health care settings.[2,3] Formal education on infection control is limited overall, and many health care workers learn on the job. However, the current training circumstances are considered insufficient, given the low level of compliance. Hence, more effective education is essential to improve infection control practices. Traditional formal education, especially in pre-graduation education, is often conducted in a lecture-style. Lecture-style education may be suitable for systematic acquisition of theory and knowledge, yet it provides little hands-on experience that is beneficial for infection control learning. Alternatively, several reports demonstrate the effectiveness of simulation-based learning.[4,5]

In recent years, virtual reality (VR) has been applied as an educational tool in various fields.[6] VR using 360-degree video was created by editing real images filmed by a 360-degree camera. The learner

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wears a goggle-type head-mounted display, and the 360-degree image changes as the body moves. This innovative technology allows learners to immerse themselves in a virtual environment from a one-person view, and this immersive experience might provide better learning outcomes.[6,7]

VR has also been used in medical education to learn various procedures, such as surgery, endoscopy, and handling situations in the emergency room.[8-11] However, there are limited reports on the use of VR for teaching infection control.[12-15] VR-based education was conducted to provide proper management and infection prevention for coronavirus disease 19 (COVID-19) patients.[12,13] VR has also been used for comprehensive infection control training to prevent postoperative wound infections and health care-associated infections in neonatal intensive care units.[14,15] Nevertheless, to the best of our knowledge, no previous report has assessed whether VR-based education is effective in improving adherence to hand hygiene and donning PPE, which are essential techniques for standard and contact precautions.

In this study, we compared the effectiveness of the two learning methods, VR learning and lecture-style learning, in imparting basic infection control procedure education, such as hand hygiene and donning PPE.

MATERIAL AND METHODS

Participants

Fourth-year medical students at a university in Japan, who agreed to participate in the study, were enrolled. These students had attended a lecture on infection control during their third year and had not yet undergone clinical training. They were randomly divided into two groups: the VR group (21 students) or the lecture group (21 students). This study was conducted separately from the normal curriculum.

Learning contents

Each group was given the same instructional content for 15 min through VR learning or conventional lecture-style learning. VR learning was performed using a fully immersive 360-degree video with a head-mounted display and a cloud-based VR delivery system developed by Jolly Good Inc. (Tokyo, Japan, Fig 1A). Lecture-style learning was performed using a PowerPoint slideshow (Fig 1B). The instructional content was prepared by the staff of the Infection Control Division of our university hospital in accordance with the World Health Organization (WHO) guideline for hand hygiene and the Centers for Disease Control and Prevention (CDC) guideline for isolation precautions.[2,16]

The VR video content for infection control was created in collaboration with Jolly Good and our University. A 360-degree camera films a doctor and nurse examining patients according to the scenario in a real-world hospital room. The contents consisted of a 5-min experience chapter from the doctor's point of view (Fig 1C) and a 10-min instructional chapter from the patient's point of view (Fig 1D). Inappropriate infection control measures allow methicillin-resistant *Staphylococcus aureus* (MRSA) to contaminate the surrounding environment and spread to other patients. Learners can experience how MRSA, visualized using computer graphics, spreads and contaminates the environment. In addition, VR provides an explanation of how to improve behavior through narration, text, photos, and videos.

In conventional lecture-style learning, students learned about the necessity and practice of hand hygiene and donning PPE as standard and contact precautions using a PowerPoint slideshow with narration, text, photos, and tables.

Fig 1. VR and lecture-style learning about infection control (A) Students using fully immersive 360-degree VR with head-mounted displays. (B) Students using a narrated PowerPoint slideshow. (C) Image from a doctor's viewpoint in the experience chapter. (D) Image from a patient's viewpoint in the instructional chapter. The purple computer graphic indicates wound infection caused by MRSA, which is also contaminating the doctor's hand.

Test procedure

The students were tested for the implementation of infection control measures using an Objective Structured Clinical Examination (OSCE) method by two assessors. Two of the four infectious disease physicians, three physicians, and one medical education specialist, who were trained to ensure uniformity in scoring methods, served as assessors. Tests were performed before and after learning. The assessors were blinded to which groups the students had been assigned. The students were requested to examine the abdomen of two patients admitted to the same room in the surgical ward. Patient 1 had a wound infection caused by MRSA after abdominal surgery and patient 2 was undergoing conservative treatment for appendicitis. No resistant organisms requiring contact precautions were detected in Patient 2. Manikin models were used for all the patients. Table 1 presents the checklist and scores. Compliance with hand hygiene before and after touching the patients and the use of aprons and gloves as contact precautions for Patient 1 were assessed. The students were asked to complete the post-test questionnaires (Table 1).

Ethics

This study was approved by the appropriate Ethics Committee.

Statistics

Comparisons of sex, age, and OSCE scores between the VR and lecture groups were performed using the χ^2 test, Fisher's exact test, or Mann−Whitney's U test. Changes between pre- and post-test in each group were evaluated using the Wilcoxon signed-rank test was used for OSCE scores. Hand hygiene compliance was evaluated using McNemar's test.

RESULTS

The median [IQR] ages of the VR group and lecture group were 22 years ([22-23]; 76.2% male) and 22 years ([22-23.5]; 71.4% male) respectively, with no difference between the groups' backgrounds.

When comparing the pre-test and post-test scores, the median scores for hand hygiene, apron-wearing, glove-wearing, and total score were significantly increased after the learning in both groups (VR group: 4-6, 0-3, 2-3, and 7-12; Lecture group: 4-6, 0-3, 2-3, and 6-9, respectively, Table 2, Fig 2A). Scores for wearing an apron indicated poor adherence before learning; however, it improved after the learning.

When comparing the scores of the VR group and the lecture group, there was no difference between the pre-test total scores (7 [5-9] vs 6 [5-7.5], P=.352). However, the VR group had significantly higher post-test total scores than the lecture group (12 [9.5-12] vs 9 [8-12], P=.024), Table 2, Fig 2A. In the category-based sub-analysis, the post-test scores of aprons and gloves tended to be higher in the VR group, but the differences were not significant (P=.076 and P=.052, respectively; Table 2).

Next, we compared compliance rates according to the timing of hand hygiene before and after learning (Fig 2B). The pre-test implementation rate of overall students was high (90.4%) before touching Patient 1, low (73.8%) after touching Patient 1 / before touching Patient 2, and lower (23.8%) after touching Patient 2. Low compliance was observed, particularly after touching patients; however, compliance tended to improve after learning in both groups.

Table 1
Evaluation using OSCE methods, checklists and scores, and questionnaires

Simulated scenarios for the test		
Perform abdominal examinations on two patients in sequence with performing infection control procedures.		
	Patient 1: Patient with postoperative wound infection caused by MRSA	
	Patient 2: Patient undergoing conservative treatment for appendicitis	
Checklists and scores		
Hand hygiene	A total of three times: Before touching the patient 1, after touching the patient 1 / before touching the patient 2, after touching the patient 2	
	Performed all three times	6
	Performed two times	4
	Performed one time	2
	Never performed	0
Apron	Worn during examination of patient 1, not worn during examination of patient 2	3
	Worn during examination of patient 1, worn during examination of patient 2 (exchanged in the process)	2
	Worn during examination of patient 1, worn during examination of patient 2 (no exchange in the process)	1
	Not worn during examination of patient 1 and patient 2	0
Glove	Worn during examination of patient 1, not worn during examination of patient 2	3
	Worn during examination of patient 1, worn during examination of patient 2 (exchanged in the process)	2
	Worn during examination of patient 1, worn during examination of patient 2 (no exchange in the process)	1
	Not worn during examination of patient 1and patient 2	0
Full scores		12
Questionnaires		
Questionnaires for VR group and Lecture group		
	Did you understand the need for infection control?	
	Did you understand the need for hand hygiene?	
	Did you understand the need for personal protective equipment?	
	Did you enjoy your learning? Were you interested in it?	
	Do you feel that the VR or lectures were useful as learning tools?	
	Do you want to attend the class using the same learning method (VR or lecture) next time?	
Questionnaires for VR group only		
	Did you feel as if you stayed in the real health care environment (realistic)?	
	Did you feel as if you were really experiencing it (immersive)?	
	Would you recommend VR to other students as a learning tool?	
	Did you feel physically ill, such as nausea, dizziness, headache, eye pain, or eye discomfort?	
	Please describe any other comments you have.	

MRSA, methicillin-resistant Staphylococcus aureus; OSCE, Objective Structured Clinical Examination; VR, virtual reality.

Table 2
Pre- and post-test scores for infection control procedures in the VR group and the lecture group

Category	VR group (n=21)		Lecture group (n=21)		*P*-value
Hand hygiene					
Pre-test	4	[2–4]	4	[3–4]	.592
Post-test	6	[6–6]*	6	[5–6]**	.437
Apron					
Pre-test	0	[0–2.5]	0	[0–0.5]	.144
Post-test	3	[2.5–3]**	3	[0–3]**	.076
Glove					
Pre-test	2	[2–3]	2	[2–3]	.817
Post-test	3	[3–3]**	3	[2–3]*	.052
Total scores					
Pre-test	7	[5–9]	6	[5–7.5]	.352
Post-test	12	[9.5–12]***	9	[8–12]***	.024

Median [IQR], * $P<.05$, ** $P<.01$, *** $P<.001$ vs Pre-test.

The results of the questionnaire using rating scales were compared between the VR group and the lecture group. There were no significant differences between the two groups regarding the students' understanding of the necessity of infection control, hand hygiene, and PPE (Fig 3A-C). However, the VR group had significantly more favorable responses than the lecture group when asked if they enjoyed the training, if it was useful as a learning tool, and if they would like to receive the same learning method the next time (Fig 3D-F). In the questionnaires for the VR group only, the VR group responded favorably to questions related to realism, immersion, and recommendations to other students (Fig 3G-I).

For the open-ended question, some students in the VR group complained of mild nausea and eye fatigue, indicating that it might be challenging to have a longer viewing time. However, none stopped learning for approximately 15 min. Other comments included that VR learning was easy to understand, motivated them to learn, allowed them to concentrate on learning, and the visualized image helped them understand how resistant bacteria adhered and spread.

DISCUSSION

When comparing the pre-test and post-test scores for infection control procedures, the scores increased after learning in both the VR and lecture groups. Furthermore, when the post-test scores of the two groups were compared, the total score of the VR group was higher than that of the lecture group. This result suggests that VR is equally or more effective than conventional lectures in educating infection control procedures.

Recently, the effectiveness of medical education using VR has been reported.[17] However, reports on the use of VR in infection control education are limited.[12-15] VR learning of the care of COVID-19 patients consisted of hand hygiene, PPE donning and doffing, and proper specimen collection.[12,13] VR-based educational program on comprehensive care to reduce health care-associated infections has also been reported.[14,15] Hand hygiene, skin care, enteral nutrition administration, and environmental disinfection in neonatal intensive care units[14] and preoperative bathing and disinfection, preoperative antimicrobials, hand disinfection, and the operating room environment to prevent surgical wound infections[15] were presented. However, there is no previous evidence focused on VR learning for basic and essential techniques, such as hand hygiene and PPE. This report suggests that VR can be a useful educational tool to increase compliance with hand hygiene and PPE as part of standard or contact precautions.

The total post-test score in the VR group was higher than that in the lecture group. Lecture-style learning is a useful method to systematically acquire a wide range of knowledge. However, it is not always possible to apply acquired knowledge to actual behavior. Contrastly, previous reports have shown the effectiveness of VR in educating on practical skills such as surgical and endoscopic techniques and emergency room triage.[8,9,11] We believe the strength of VR is that it is suitable for acquiring practical skills as well as knowledge through scenario-based immersive experiences.[6,7]

However, the limitations of VR are that it requires considerable time, effort, and high cost. The VR creation process involves many staff members and consists of several steps such as theme selection, scenario preparation, camera setting, video filming, and video editing.[18] Even if the creation is carried out in collaboration with a VR production company, as in this study, considerable effort may be involved in the creation process. This content was created by nine university staff and seven VR production company staff, and cost approximately $65,000 US. Each set of goggles and application costs approximately $1,000 US. In contrast, the lecture slides were prepared by three university staff members and took approximately twelve hours to complete. However, some argue that despite the high initial cost, VR has the advantage of being available to a large number of learners and can be used over a long period with limited additional costs.[19] Since infection control is universal, VR videos, once created, can be used not only by medical students, but also by

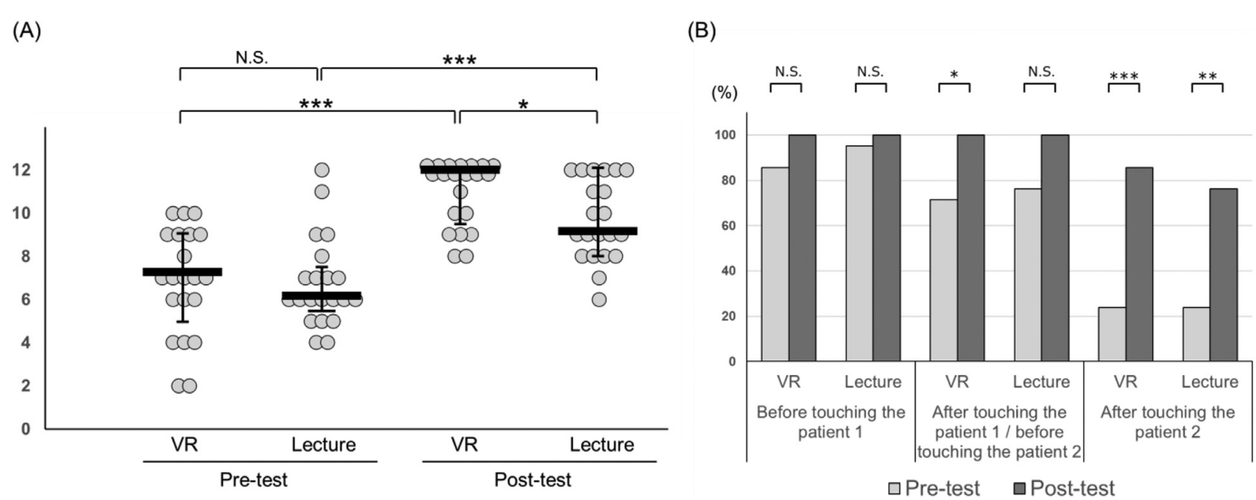

Fig 2. Effectiveness of two learning methods in educating infection control procedures (A) Total scores for infection control procedures before and after learning in the VR and lecture groups. The full score is 12 points. (B) Changes in hand hygiene compliance before and after the learning in the VR and lecture groups. *$P<.05$, **$P<.01$, ***$P<.001$, NS, not significant.

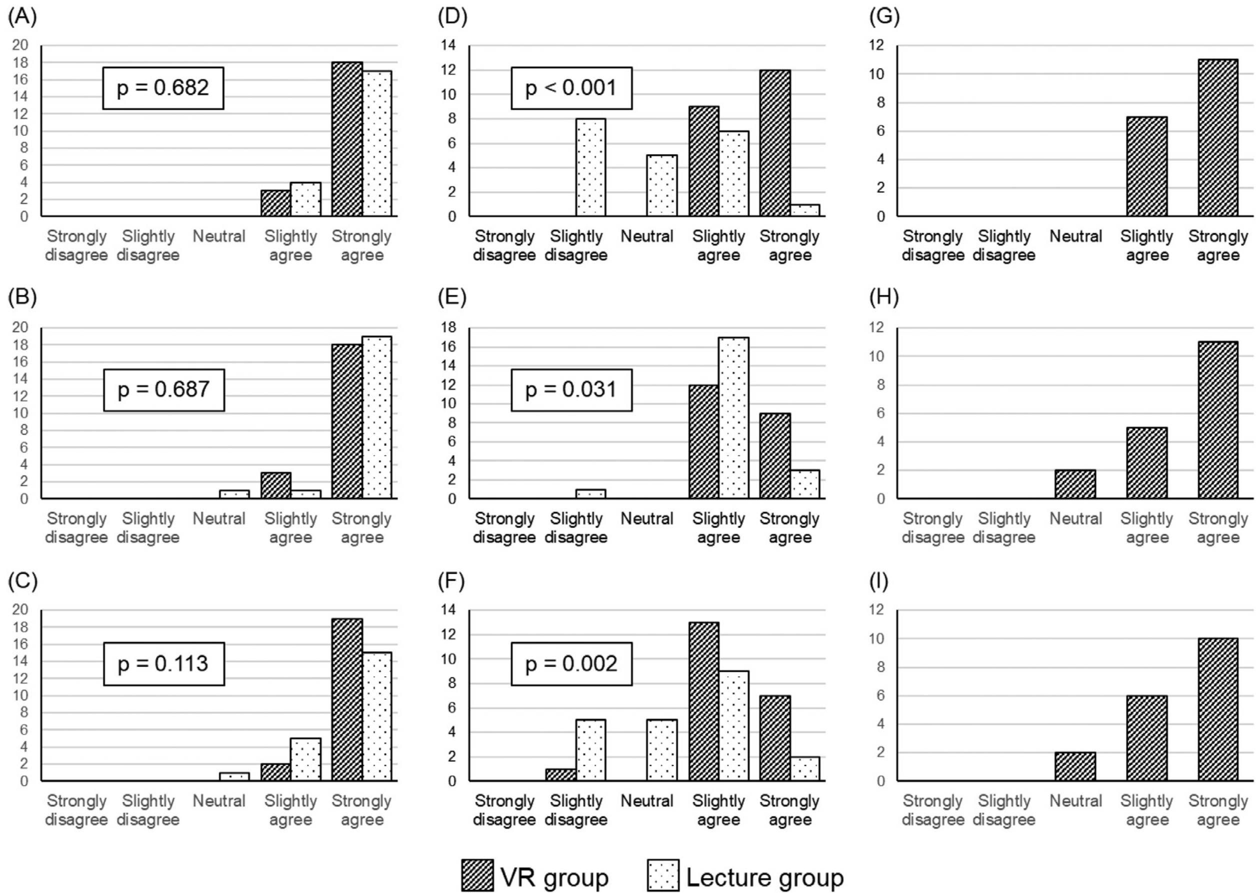

Fig 3. Results of Questionnaires. (A−F) Comparisons of the questionnaire results between the VR group and the lecture group. Questionnaires: (A) Did you understand the need for infection control? (B) Did you understand the need for hand hygiene? (C) Did you understand the need for personal protective equipment? (D) Did you enjoy your learning? Were you interested in it? (E) Do you feel that the VR or lectures were useful as learning tools? (F) Do you want to attend the class using the same learning method (VR or lecture) next time? (G) Did you feel as if you stayed in the real healthcare environment (realistic)? (H) Did you feel as if you were really experiencing it (immersive)? (I) Would you recommend VR to other students as a learning tool?

residents, physicians, nurses, and other medical personnel, and can be used for a long time.

In the questionnaires, more students in the VR group compared with the lecture group answered that they enjoyed learning, that it was useful as a learning tool and that they would like to take the class using the same learning method next time. These results suggest that VR increased students' learning motivation and satisfaction. Conventional lecture-style learning tends to be one-way teaching from the teacher to the students, which can lead to a lack of motivation and concentration. The VR provides the students with a simulated experience as if they stay in a real-world hospital environment and an immersive experience from the point of view of health care providers or patients. These VR characteristics are expected to increase learners' motivation and concentration.[7]

During the COVID-19 pandemic, medical students were restricted from clinical training in the health care environment. Therefore, a new modality for medical education that does not involve face-to-face contact is needed.[20] VR learning may offer clinical training without the risk of exposure to infection. In addition, VR can be used on-demand, away from the clinical and social restrictions caused by the pandemic.

Hand hygiene is the most important procedure for preventing health care-related infections. However, adherence is low, as the World Health Organization revealed that the average hand hygiene compliance was 38.7%.[2] Despite several educational measures, such as poster displays, direct observation surveys, and usage feedback, improvement of compliance remains a challenge.[21,22] This study also showed low compliance with hand hygiene, especially after touching the patient; however, the compliance rates increased after learning. The VR we used allowed learners to experience the visualized MRSA spreading and contaminating the surrounding environment from the patient's viewpoint and illustrates how to improve problematic behaviors. This simulated experience may lead to greater recognition of the necessity for hand hygiene.

This study has several limitations. First, the instructional contents of the VR group and the lecture group are not identical. However, important points, such as knowledge and practical procedures for infection control, were included in both instructional contents. Second, we did not verify whether the effectiveness of VR learning on infection control procedures was sustained in the long term. Third, although this study observed poor adherence to hand hygiene and PPE use, the data were derived from pre-graduate students and may not reflect the actual adherence among healthcare providers. In the future, it may be beneficial to assess adherence among healthcare providers and introduce VR learning for improvement.

CONCLUSIONS

The implementation of infection control procedures such as hand hygiene, apron-wearing, and glove-wearing improved after the learning in both groups. However, interestingly, the VR group had higher total scores than the lecture group. In addition, the questionnaires revealed that the VR group had more favorable responses to the learning methods. VR can be a useful tool for appropriate infection control procedure training and practice.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

This study was approved by the appropriate Ethics Committee for Epidemiology of Hiroshima University (E-2709).

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