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Students' Perception of Remote Extended Reality Simulation Systems Using Patient-specific Three-Dimensional-printed Models in Endodontic Education: A Pilot Study

Riyadh ALROOMY,[1] Munirah ALMIMONI,[1] Abdulaaly ALOTAIBI,[1] Ahad ALMUTAIRI,[1] Ebtesam ALYAHYA,[1] Motoharu UNOZAWA,[2] Takahito KAKUMOTO,[3] Katsushi OKAZAKI[4]

[1]Department of Restorative and Prosthodontic Dental Sciences, College of Dentistry, Majmaah University, AlMajmaah, Saudi Arabia
[2]Dental Prediction Co., Ltd., Tokyo, Japan
[3]Kakumoto Dental Clinic, Tochigi, Japan
[4]Department of Endodontics, New York University, College of Dentistry, DenPre Faculty, New York, USA

ABSTRACT

Objective: Extended reality (XR) technology using head-mounted devices enables the operator to visualise anatomical structures. We aimed to investigate student perceptions regarding applying XR simulation for transferring endodontic educational information between a lecturer in Japan and students in Saudi Arabia.

Methods: In this study, the students engaged with an XR simulation system and viewed teeth in virtual reality (VR). Pictures of dental anatomy were shown in the VR space, allowing participants to manipulate them. Then, the participants viewed a patient-specific three-dimensional printed model and three-dimensional root canal access guide in a second VR area. Before the sessions, the students completed a questionnaire on demographic data and information concerning their VR experience. After the sessions, they completed a questionnaire evaluating the XR simulation system. The questionnaire included questions on dental anatomy, root canal access, usability, emotional impression, and data transfer.

Results: Eleven 5th-year dental students, comprising six male and five female students, were enrolled; three of them had previous VR experience, whereas eight did not. The highest levels of satisfaction were noted in the tooth anatomy (4.6±0.4) and emotional impression (4.5±0.5) domains, whereas the lowest level was noted in the data transmission domain (3.5±0.9). Female participants and those without previous VR experience reported higher satisfaction levels across questionnaire domains compared to male participants and those with previous VR experience.

Conclusion: XR can be successfully used in dental education and integrated into online lectures. Restrictions on education caused by health crises can be averted by using XR. Further, fifth-generation networks can offer better data transmission than wireless fidelity.

Keywords: Endodontic education, extended reality, virtual reality, wireless fidelity network

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Address for correspondence:
Riyadh Alroomy
Department of Restorative and Prosthodontic Dental Sciences, College of Dentistry, Majmaah University, AlMajmaah, Saudi Arabia
E-mail: r.alroomy@mu.edu.sa

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HIGHLIGHTS

- This pilot study examined students' perceptions regarding applying XR simulation for transferring endodontic educational information between a lecturer in Japan and students in Saudi Arabia.
- XR can be used in dental education and effectively integrate with online lecture formats.
- XR can help prevent disruption to education during crises that restrict gathering.

INTRODUCTION

The introduction of extended reality (XR) technology has significantly transformed the use of virtual reality (VR) and augmented reality (AR) in the fields of medicine and dentistry by improving the efficiency of medical and dental systems as well as medical education standards. XR technology, specifically VR and AR, is increasingly used in dental education to augment students' comprehension of dental anatomy and spatial relationships among various dental structures (1). In conjunction with fifth-generation (5G) networks, XR technology has facilitated remote medical education and consultation, giving individuals in rural areas greater access to healthcare. VR technology has been used increasingly in clinical practice for three-dimensional (3D) diagnosis, treatment planning, surgical support, clinical simulation-based learning, medical consultation, preclinical training, and academic research (2).

Outbreaks of infectious diseases and biothreats, such as the coronavirus pandemic, are complex public health crises requiring swift management. Thus, it is crucial to implement educational reforms that incorporate new technologies to ensure that public health professionals are well-equipped to effectively address these challenges (3, 4). VR technology in medicine can integrate computer-generated animations and illustrations; however, this technology lacks diversity and cannot use actual patient data (5). Consequently, sharing patient data or communicating in real-time in a virtual environment is impossible in educational or clinical settings.

XR technology can create a virtual space where the real world merges and interacts with the virtual world (6). It is an effective medical and dental education tool for students without practical experience. The most advanced XR technology in the world, developed in Japan, can implement highly accurate, seamless, and real-time simulation systems using virtual 3D images and holograms to provide an immersive experience. This innovative system can become the standard for education and healthcare support. XR, as a supplementary educational tool, has enhanced students' knowledge and skills related to dental procedures (7). Students typically report dissatisfaction regarding the traditional teaching techniques (8). Those who participate in a dental operator simulation acquire a higher level of knowledge than those who receive instructions only via standard lectures or preclinical laboratories (9–11). Using XR as a learning aid can facilitate a better understanding of dental operations among students (7). Further, head-mounted devices (HMDs) enable the operator to visualise anatomical structures or organs as structures floating in the virtual space. Moreover, operators can zoom in and out of the virtual 3D models by pinching and pulling control buttons with their fingers. Using an HMD can also facilitate immersive experiences in a given 3D setting, allowing the user to virtually walk into 3D scenarios and visualise 3D models in any direction. XR technology plays an important role in creating an augmented sense of presence (12). Therefore, we aimed to examine the effectiveness of XR technology in the field of endodontic education. We examined students' perceptions of XR simulations applied to lectures involving a lecturer in Japan and students in Saudi Arabia, which were enabled by a wireless fidelity (Wi-Fi) network connection.

MATERIALS AND METHODS

This pilot study was approved by the Research Ethics Committee of Majmaah University (approval number HA-01-R-088). All research procedures adhered to the ethical standards outlined in the 1964 Declaration of Helsinki and its subsequent amendments. Dental students from our university who consented to participate were enrolled in this study. Only students who had completed the preclinical operating skills training course were included.

Developing 3D Virtual Model and Observation

Using open-source software tools, a 3D virtual model was created by processing DICOM files derived from Cone Beam Computed Tomography (CBCT). Initially, a 3D slicer (https://www.slicer.org) was employed to comprehensively analyse the internal structures, generating a 3D dataset. Subsequently, Blender (https://www.blender.org/) was utilised to optimise the 3D model, refining it to enhance its quality. The final step involved exporting the model in STL format, with segmentation into distinct layers for further manipulation.

After optimisation, the individual STL data segments were imported into the Holoeyes XR application, version 2.6 (Holoeyes Inc., Tokyo, Japan). This application served as a platform for the visualisation and interaction with the 3D virtual model. A VR head-mounted display, specifically the Meta Quest 2 (Meta Platforms, Inc., Menlo Park, CA, USA) was employed to enable immersive exploration of the intricacies of the model.

In summary, this workflow facilitated the transformation of medical imaging data from CBCT into a highly detailed 3D virtual model, rendering it suitable for various applications, including immersive visualisation via VR technology.

Students' Experience

This study used Oculus2 (Microsoft Corp., Redmond, WA, USA) as the HMD. The students participated in a video conference via Zoom and received safety and operation instructions for the equipment and procedures. Then, they attended two separate simulation sessions after being instructed on using HMDs with the XR simulation system connected using a Wi-Fi network. The students wore the Oculus2 to enter the XR simulation system and visualised virtual images of teeth in VR space (Fig. 1).

A researcher (KO) demonstrated the tooth's anatomy in VR space, and the participants were allowed to manipulate virtual images of teeth in the VR space to understand the tooth's anatomy. The participants subsequently entered the second VR space, where they could visualise virtual images of a patient-specific 3D-printed model and 3D-root canal access guide. In this space, the researcher (KO) demonstrated the procedure for accessing root canals using the 3D guide in VR space. Then, the participants were allowed to manipulate the 3D-printed model and utilise the 3D-access guide to understand the concept of 3D-guided treatment and procedures within the VR space (Fig. 2).

Before the sessions, a questionnaire concerning the participants' demographic characteristics and previous experience with VR was administered (11 students). A second questionnaire with items pertaining to their perception of the learning

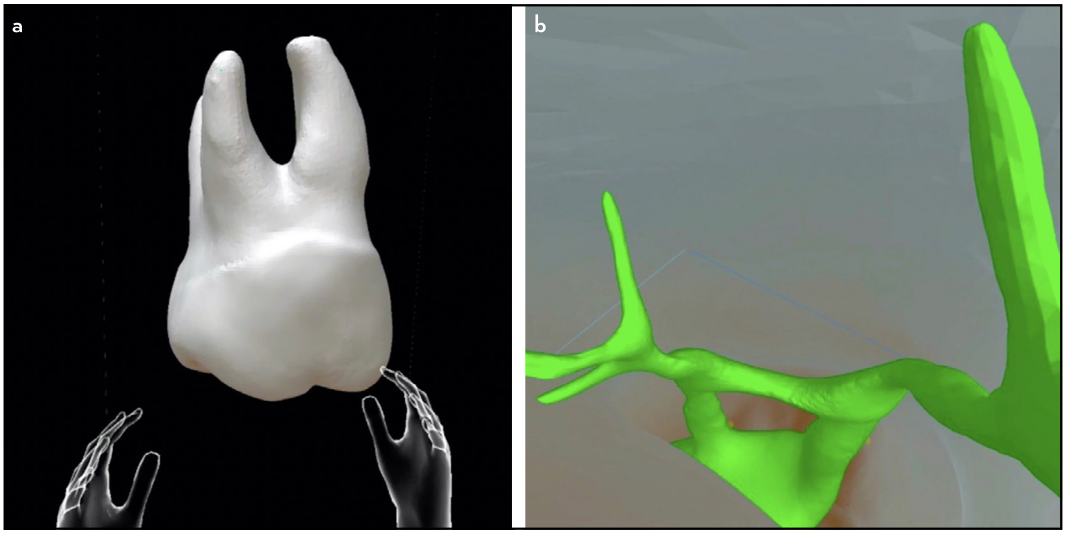

Figure 1. VR images of teeth. (a) VR image of the maxillary first molar, (b) VR image of dental pulp tissue
VR: Virtual reality

approach using the XR simulation system was administered via an interview after the sessions to assess the participant's perceptions. The questionnaire encompassed the following five domains: tooth anatomy, root canal access, usability, emotional impression, and data transmission.

Statistical Analysis

Data were retrieved from Google Forms and converted into a worksheet in Excel format. The worksheet was coded, double-checked, and transferred to IBM SPSS Statistics (v25.0 for Windows; IBM Corp., Armonk, NY, USA) for statistical analyses. The results of the questionnaire domains (the score is out of 5 because it is range from strongly disagree to strongly agree) and total scores were expressed as means and standard deviations (M±SDs), whereas the detailed responses of the whole sample are expressed as frequencies and percentages. The differences in responses of the participants according to sex and previous VR experience were evaluated using the independent t-test. Statistical significance was set at a p-value of <0.05.

RESULTS

Eleven 5th-year dental students (sex, six [54%] male and five [46%] female) were enrolled in this study. Among the 11 participants, three (27.3%) had previous VR experience, whereas eight (72.7%) had no previous VR experience. Table 1 presents the means and SDs of the questionnaire domains and the total score of the responses for the whole cohort according to sex and previous VR experience. The domains with the highest levels of satisfaction were tooth anatomy (4.6±0.4) and emotional impression (4.5±0.5), whereas the domain with the lowest level of satisfaction was data transmission (3.5±0.9). Female participants reported a higher level of satisfaction than male participants for all questionnaire domains. The participants with no previous VR experience reported higher satisfaction for all questionnaire domains than those with previous VR experience.

No significant differences were observed between the satisfaction levels of male and female participants, except for the domain of data transmission (p=0.007) and total scores (p=0.045) (Table 2). The highest mean difference between the sexes was observed in the total scores (mean difference, -11.9; 95% confidence interval [CI], -23.6–-0.3), whereas the lowest mean difference was observed in the domain of root canal access (mean diff., -0.2; 95% CI, -1.1–0.7). Table 3 presents the difference between the participants according to previous VR experience. No significant differences were observed between the participants with no previous VR experience and their counterparts across all questionnaire domains and in the total score (p>0.05). The highest mean difference was observed in the total score (mean diff., 4.7; 95% CI, -11.3–20.8), whereas the lowest mean difference was observed in the domain of emotional impression (mean diff., 0.0; 95% CI, -0.7–0.8).

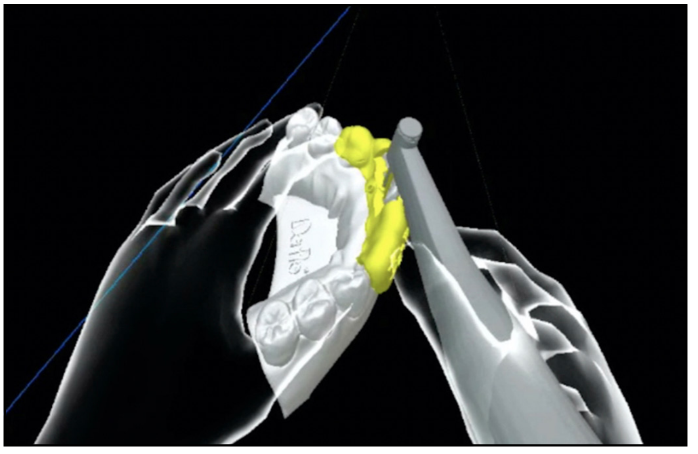

Figure 2. A VR image created using a set of 3D endo-guide training mode
VR: Virtual reality, 3D: Three-dimensional

Table 4 presents the detailed responses of the participants to all the questions. Most responses were 'completely agree', followed by 'moderately agree' and 'neutral'. There was only one response of 'completely disagree' in the domain of tooth anatomy. There was also one response of 'completely disagree' in the domain of root canal access; in contrast, the numbers of 'completely disagree' and 'moderately disagree' responses were higher in the domain of data transmission (Table 4).

TABLE 1. Descriptive statistics of the questionnaire domains and total score of the responses for the whole sample according to sex and VR experience

Domain		Sex		Experience	
	All	Male	Female	No	Yes
Tooth anatomy	4.6±0.4	4.5±0.4	4.8±0.4	4.7±0.5	4.5±0.4
Root canal access	4.2±0.7	4.2±0.8	4.4±0.6	4.3±0.7	4.2±0.7
Usability	4.4±0.6	4.1±0.7	4.7±0.4	4.5±0.6	4.1±0.8
Emotional impression	4.5±0.5	4.4±0.5	4.7±0.4	4.6±0.5	4.5±0.3
Transmission of the data	3.5±0.9	2.9±0.6	4.2±0.7	3.6±1.0	3.1±0.7
Total score	94.1±10.2	88.7±9.7	100.6±6.7	95.4±11.2	90.7±7.6

VR: Virtual reality.

TABLE 2. Sex differences in relation to different domains and the total score of the responses

Domain	Mean difference	95% CI of the difference		
		Lower	Upper	p*
Tooth anatomy	-0.4	-0.9	0.2	0.158
Root canal access	-0.2	-1.1	0.7	0.625
Usability	-0.7	-1.4	0.1	0.081
Emotional impression	-0.3	-0.9	0.3	0.278
Data transmission	-1.4	-2.3	-0.5	**0.007**
Total score	-11.9	-23.6	-0.3	**0.045**

*: Independent t-test was used; a p-value of <0.05 was considered significant. CI: Confidence interval

TABLE 3. Differences according to VR experience in relation to different domains and the total score of the responses

Domain	Mean difference	95% CI of the difference		
		Lower	Upper	p*
Tooth anatomy	0.1	-0.5	0.8	0.649
Root canal access	0.1	-1.0	1.1	0.897
Usability	0.3	-0.7	1.3	0.482
Emotional impression	0.0	-0.7	0.8	0.961
Data transmission	0.5	-0.9	2.0	0.431
Total score	4.7	-11.3	20.8	0.524

*: Independent t-test was used; a p-value of <0.05 was considered significant. VR: Virtual reality, CI: Confidence interval

DISCUSSION

In this study, we aimed to investigate the efficacy of XR technology in improving endodontic education standards. The highest level of participant satisfaction was observed in the domain of tooth anatomy, followed by the domain of emotional impression. In contrast, the lowest level of participant satisfaction was observed in the domain of data transmission, which may be attributed to the utilisation of Wi-Fi instead of 5G technology. Furthermore, female participants reported greater satisfaction across all questionnaire domains than their male counterparts. Participants lacking experience in VR reported higher satisfaction levels across all questionnaire domains than their counterparts with previous VR experience. Using XR technology to train future healthcare professionals may profoundly impact the medical field by improving the quality of training. In a previous study, most participants expressed favourable perceptions and experiences using VR dental simulators for training purposes (13). Several previous studies have demonstrated the efficiency of this technology (5, 14, 15).

A recent study reported that XR technology can enhance students' operative abilities and foster increased self-assurance (16). A previous study on the impact of virtual education on students' understanding of dental anatomy reported favourable outcomes (7). XR technology offers several advantages, such as improved visual representation, interactive educational experiences, enhanced hand-eye coordination, and integration of tactile feedback as an additional aspect, potentially transforming dental education (17–19). Moreover, the findings of this study indicate that female participants expressed higher levels of satisfaction across every aspect of the questionnaire compared to their male counterparts, aligning with previous research (20). The observed disparity in perception may be related to variations in levels of technological familiarity or ease of use rather than being primarily driven by sociocultural factors (21). Nevertheless, XR technology cannot wholly replace conventional dental models that offer a more accurate simulation of clinical endodontics procedures performed on actual patients. XR, encompassing VR and AR, is a valuable supplementary tool in dentistry education.

Some factors have limited the implementation and utilisation of XR in dental education. Numerous clinical trials have systematically assessed the efficacy of VR and AR technologies in dental education. A notable absence of standardisation and accreditation characterises VR, AR systems, and content. Moreover, the accessibility of VR and AR systems may be limited by the requirement of large, immobile, and expensive hardware components. Thus, the implementation of these technologies in dental education programs remains challenging. VR and AR systems also face significant hardware and software limitations, such as the absence of force feedback (2, 17, 22, 23).

This study had some limitations. First, the sample size was considerably small, with only 11 participants. Consequently, the generalisability of the findings is not high, and the results must be interpreted with caution owing to the preliminary nature of this pilot study. Further studies are needed

TABLE 4. Frequency and percentages of different categories of responses to the questionnaire

Question	Completely disagree	Moderately disagree	Neutral	Moderately agree	Completely agree
Regarding tooth anatomy					
Is the ability to visualise the internal or external tooth anatomy useful?	0 (0.0)	0 (0.0)	0 (0.0)	3 (27.3)	8 (72.7)
Is the ability to understand the three-dimensional location of the root canals useful?	1 (9.1)	0 (0.0)	0 (0.0)	0 (0.0)	10 (90.9)
Is the ability to identify the configuration of the root canals useful?	0 (0.0)	0 (0.0)	0 (0.0)	3 (27.3)	8 (72.7)
Is the ability to identify the existence of confluence in canals useful?	0 (0.0)	0 (0.0)	2 (18.2)	2 (18.2)	7 (63.7)
Is the ability to fully comprehend the root canal anatomy useful?	0 (0.0)	0 (0.0)	1 (9.1)	2 (18.2)	8 (72.7)
Regarding the '3D guide of root canal access for a calcified canal'					
Is the ability to understand the designs and elements of the 3D guide useful?	0 (0.0)	0 (0.0)	2 (18.2)	3 (27.3)	6 (54.5)
Is the ability to understand the optimal fitting of the 3D guide on the teeth useful?	0 (0.0)	0 (0.0)	2 (18.2)	3 (27.3)	6 (54.5)
Is the ability to understand the design of the bur for root canal access with a 3D guide useful?	0 (0.0)	0 (0.0)	2 (18.2)	5 (45.5)	4 (36.4)
Is the ability to identify the configuration of the calcified root canals useful?	0 (0.0)	0 (0.0)	1 (9.1)	4 (36.4)	6 (54.5)
Is the ability to understand the depth of the bur insertion useful?	1 (9.1)	0 (0.0)	3 (27.3)	2 (18.2)	5 (45.5)
Regarding 'Usability'					
Is the ability to manipulate the teeth useful?	0 (0.0)	0 (0.0)	1 (9.1)	5 (45.5)	5 (45.5)
Is it easy to manipulate the 3D guide?	0 (0.0)	0 (0.0)	0 (0.0)	7 (63.6)	4 (36.4)
Is it easy to scale the images?	0 (0.0)	0 (0.0)	3 (27.3)	1 (9.1)	7 (63.6)
Regarding 'Emotional impression'					
Does 3D rendering make it easier to understand?	0 (0.0)	0 (0.0)	1 (9.1)	5 (45.5)	5 (45.5)
Is it fun, just like playing a game?	0 (0.0)	0 (0.0)	1 (9.1)	1 (9.1)	9 (81.8)
Does it facilitate fast learning?	0 (0.0)	0 (0.0)	2 (18.2)	3 (27.3)	6 (54.5)
Does interacting with a clinical tutor in VR space promote focus and learning?	0 (0.0)	0 (0.0)	1 (9.1)	3 (27.3)	7 (63.6)
Is it useful for teaching?	0 (0.0)	0 (0.0)	0 (0.0)	3 (27.3)	8 (72.7)
Regarding 'Transmission of data images'					
Do you feel comfortable with the image quality?	0 (0.0)	0 (0.0)	1 (9.1)	7 (63.6)	3 (27.3)
Do you feel that the response of images is delayed?	2 (18.2)	3 (27.3)	4 (36.4)	0 (0.0)	2 (18.2)
Do you feel a latency time of more than 1 s is present?	3 (27.3)	1 (9.1)	4 (36.4)	0 (0.0)	3 (27.3)
Are you frustrated by the delay of the image?	0 (0.0)	2 (18.2)	2 (18.2)	1 (9.1)	6 (54.5)

3D: Three-dimensional, VR: Virtual reality to substantiate the findings of this study. Second, while 5G networks are known to yield more optimal outcomes, this study used Wi-Fi technology. Third, it is imperative to acknowledge that the study did not investigate the potential long-term effects of XR simulation systems on the educational process of dental students in endodontic courses who underwent training with XR technology.

CONCLUSION

In this study, participants expressed the highest satisfaction with the domain of tooth anatomy, followed by emotional impressions. In contrast, the participants were least satisfied with the domain of data transmission. Furthermore, female participants and those without VR experience had higher satisfaction levels across all questionnaire domains compared to male participants and those with previous VR experience. Our findings suggest that XR can be successfully used in dental education, and online lectures should integrate XR. With the use of XR, restrictions on access to education due to health crises in the future can be averted. Furthermore, 5G can offer better data transmission in XR simulations than Wi-Fi.

Disclosures

Ethics Committee Approval: The study was approved by the Majmaah University Research Ethics Committee (no: HA-01-R-088, date: 27/01/2022).

Authorship Contributions: Concept – R.A., K.O.; Design – M.U., T.K.; Supervision – M.A., A.Alo., A.A., E.A.; Funding – R.A., K.O.; Data collection and/or processing – M.A., A.Alo., A.A., E.A.; Data analysis and/or interpretation – M.U., T.K.; Literature search – M.U., T.K.; Writing – M.A., A.Alo., A.A., E.A.; Critical review – R.A., K.O.

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