Augmented Reality Improved Knowledge and Efficiency of Root Canal Anatomy Learning: A Comparative Study

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Abstract

Teaching root canal anatomy has traditionally been reliant on static methods, but recent studies have explored the potential of advanced technologies like augmented reality (AR) to enhance learning and address the limitations of traditional training methods, such as the requirement for spatial imagination and the inability to simulate clinical scenarios fully. This study evaluated the potential of AR as a tool for teaching root canal anatomy in preclinical training in endodontics for predoctoral dental students. Six cone beam computed tomography (CBCT) images of teeth were selected. Board-certified endodontist and radiologist recorded the tooth type and classification of root canals. Then, STereoLithography (STL) files of the same images were imported into a virtual reality (VR) application and viewed through a VR head-mounted display. Forty-three third-year dental students were asked questions about root canal anatomy based on the CBCT images, and then, after the AR model. The time to respond to each question and feedback was recorded. Student responses were paired, and the difference between CBCT and AR scores was examined using a paired-sample *t*-test and set to $p = 0.05$. Students demonstrated a significant improvement in their ability to answer questions about root canal anatomy after utilizing the AR model ($p < 0.05$). Female participants demonstrated significantly higher AR scores compared to male participants. However, gender did not significantly influence overall test scores. Furthermore, students required significantly less time to answer questions after using the AR model (M = 4.09, SD = 3.55) compared to the CBCT method (M = 15.21, SD = 8.01) ($p < 0.05$). This indicates that AR may improve learning efficiency alongside comprehension. In a positive feedback survey, 93% of students reported that the AR simulation led to a better understanding of root canal anatomy than traditional CBCT interpretation. While this study highlights the potential of AR in learning root canal anatomy, further research is needed to explore its long-term impact and efficacy in clinical settings.

Keywords: virtual reality; root canal configuration; endodontics; CBCT; dental education

1. Introduction

Immersive technologies have the potential to provide a practical approach to learning in dental education by being integrated into existing teaching curricula [1]. It provides new opportunities for collaboration and interaction among students and supervisors that were previously impossible [2]. Students are more interested when advanced education methods are being used [3]. Cross or extended reality (XR) represents an umbrella term that collectively refers to virtual reality (VR), augmented reality (AR), and mixed reality (MR), which are based on spatially immersive environments with immersive learning. AR creates a completely virtual space generated by computer graphics for the user's eyes to replace the actual space. AR utilizes head-mounted displays with stereo headphones and motion-tracking systems in medical anatomy education [2,4].

XR technologies have emerged with promising potential to revolutionize dental education methods to train students before encountering actual patients. Subjective surveys favored the AR technique in gaining knowledge and skills in operative dentistry [4]. In-depth knowledge of identifying all canal anatomy is fundamental to learning skills needed to develop adequate quality root canal treatment and prevent mishaps. While traditional skill training remains effective in teaching root canal anatomy, it requires spatial imagination and inherits limitations to simulate clinical settings [5]. Certain endodontic competency skills mandate repeated projects and long practice [6]. Therefore, teaching root canal anatomy has recently been investigated to utilize AR technology [7]. A recent study indicated that most dental students supported using VR implementation to supplement traditional methods of acrylic teeth [8]. Endodontic residents trained in a virtual environment using the 3D computerized model generated from the original cone-beam computed tomography (CBCT) image data improved endodontic microsurgery performance [9].

While AR has shown promise in various dental applications, its utility in teaching root canal anatomy remains relatively unexplored. Challenges in developing accurate virtual models of root canal anatomy, primarily due to image artifacts and complex anatomical segmentation, have hindered the advancement of AR-based learning in this domain. To fully realize the potential of AR in endodontic education, a robust database of diverse and complex root canal anatomy cases is essential for creating practical AR simulations.

The current study investigated the efficacy of AR as a pedagogical tool for enhancing dental students' comprehension of root canal anatomy. The null hypothesis posits no significant difference in the student's ability to identify root canal anatomy using AR compared to CBCT alone. We utilized patient-specific 3D virtual models derived from CBCT data to test this hypothesis. Predoctoral dental students participated in a remote learning environment via the metaverse, engaging with both CBCT images and AR models of various teeth to explore root canal morphology.

2. Materials and Methods

The institutional review board reviewed and approved the study protocol (IRB No 22-7220).

2.1. CBCT Scans Selection

All CBCT images underwent rigorous de-identification to safeguard patient confidentiality, removing personal identifiers such as medical record numbers, names, age, and gender. A unique identifier was assigned to each image to prevent data linkage. The samples included different root canal morphologies exhibiting complex variations (**Table 1**). Two board-certified endodontists independently classified tooth type and root canal morphology based on the Weine classification system [10]. CBCT images were acquired using a Carestream Dental CS 9300 unit (Rochester, NY, USA) with the following parameters: 10 × 10 cm field of view, 0.18 mm voxel, 90 kV, and 5 mA. Image analysis was performed using CS 3D Imaging software (version 3.10.38) to enable multiplanar reconstructions.

Table 1. A comprehensive overview of the mean scores, standard deviations, and statistical comparisons between the CBCT and AR groups for the total score and individual tooth questions.

2.2. Developing AR Model

The 3D virtual models were generated from dental CBCT scans in DICOM format via a multi-step software pipeline. Initially, 3Dslicer (**https://slicer.org/**) comprehensively segmented internal structures, creating a structured 3D dataset. Blender (**https://www.blender.org/**) optimized this dataset, enhancing model quality and reducing unnecessary complexity. Finally, the segmented model was exported in STereoLithography (STL) format with distinct layers for further manipulation. For visualization and interaction within the Holoeyes XR application (version 2.6, Holoeyes Inc., Minato City, Japan), individual STL segments were imported. An immersive exploration of the model's intricacies was facilitated using a Meta Quest 2 VR head-mounted display (HMD) (Meta Platforms, Inc., build 68.0, Menlo Park, CA, USA **https://www.meta.com/help/quest/articles/whats-new/release-notes/**). **Figure 1** provides a visual representation of these processes.

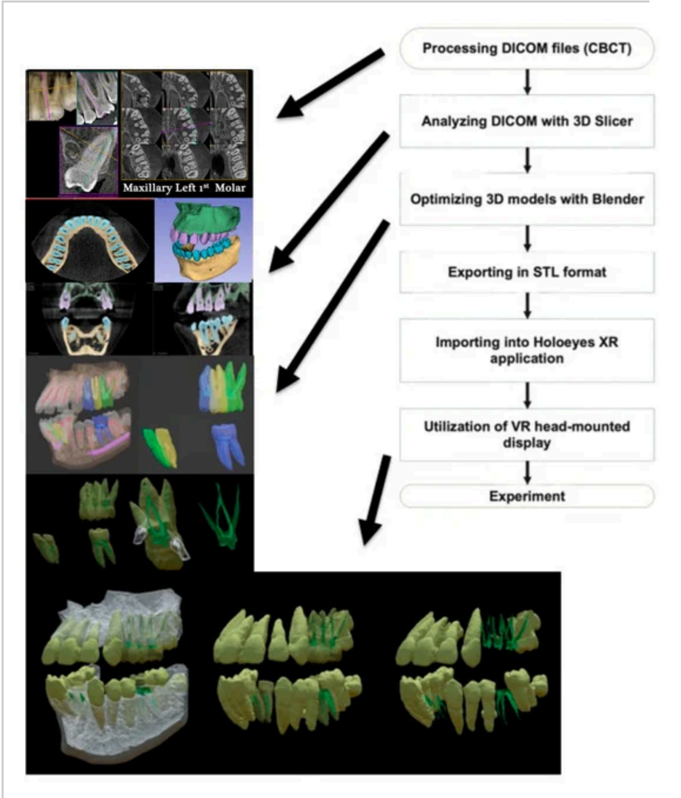

Figure 1. Generation and Optimization of a Virtual 3D Model from DICOM Data for AR Visualization. A 3D virtual model was created from CBCT scans using open-source 3Dslicer and Blender. 3Dslicer analyzed internal structures and generated 3D data. Blender refined the model's quality. The model was exported as segmented STL files into Holoeyes XR application version 2.6 for visualization and interaction. A Meta Quest 2 VR headset enabled immersive exploration of the model's intricacies. Key software utilized: 3Dslicer (data generation), Blender (optimization), Holoeyes XR application (visualization), Meta Quest 2 headset (interaction).

2.3. Participants Pre-Training

A total of 43 third-year predoctoral dental students participated in the study and signed a written consent form. Participants were given the following training before experimenting. An endodontics faculty member gave a twenty-minute online lecture focusing on root canal morphology, accessory canals, anastomosis, and root canal configuration classification. The class did not include AR models or CBCT images.

Before the main experiment, students received dedicated training in anatomical identification and assessment utilizing CBCT images of teeth, not included in the study, on a 2D monitor. This training focused on axial, mesiodistal, and buccolingual sections. Students were trained on HMDs with samples of a 3D virtual model provided for training and were not included in the actual experiment. By moving from place to place, students could observe the root canal morphology from all directions. Students were informed that they would be withdrawn from the study if they reported any side effects, including ocular discomfort, nausea, dizziness, and headaches.

2.4. Implementation Steps

A quasi-experimental design was used. All participants underwent two learning modalities: CBCT image analysis and AR-based tooth model exploration. A four-week interval was introduced between the two sessions to minimize carryover effects. Participants viewed CBCT images of selected teeth on a 2D monitor. Following each scan, they completed a questionnaire assessing their understanding of root canal morphology, adapted from a previous study [7], with some modifications. For each tooth, three questions were asked: (1) the number of root canals present, (2) detecting merging/branching of canals, and (3) Weine's classification of a root canal configuration.

Participants interacted with 3D virtual tooth models with the instructor in an immersive AR environment using HMDs (**Figure 2**). Then, they answered identical anatomical identification questions previously posed during the CBCT exercise. Students did not know the teeth used in the AR model.

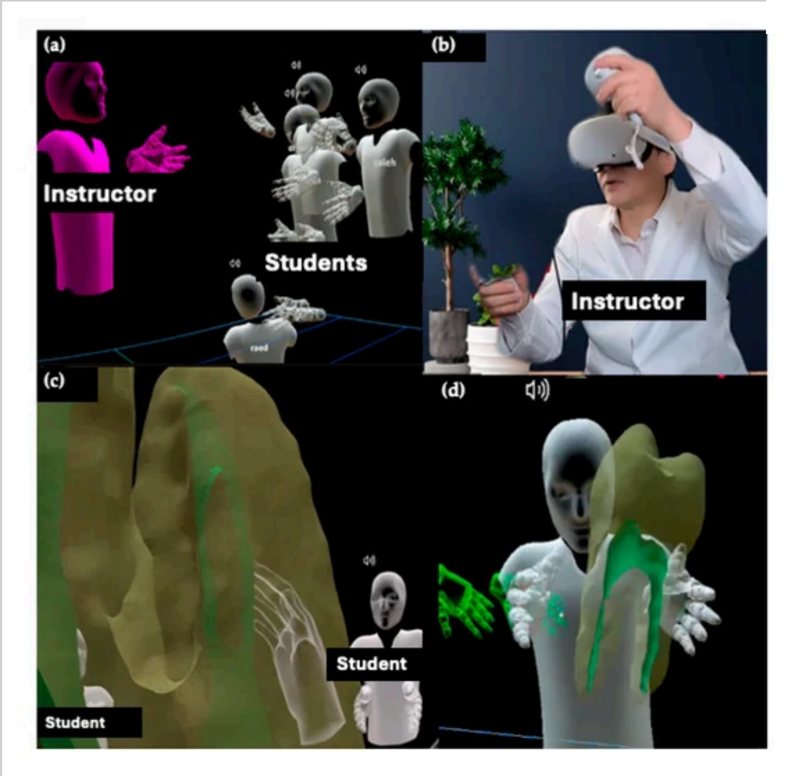

Figure 2. Screen captures illustrate the virtual learning environment (**a**), where students collaborate with a virtual instructor to explore root canal system complexities (**b**). Student performance is assessed through timed tasks and subsequent knowledge-based questions (**c**,**d**).

Students were given a timer to record the time needed to answer the three questions related to each tooth using CBCT or AR models. In addition to completing the questionnaire, students were asked to fill out the following survey after completing each session:

(a) From a didactic point of view, did the VR simulation result in a better or worse comprehension of the root canal anatomy than CBCT? Or did both methods perform the same?
(b) Did you face dizziness or disorientation during the VR simulation?

2.5. Statistical Analysis

A power sample size calculation was predetermined to be 80% with an effective size of 0.42. Answers were scored with correct answers coded as 1 and incorrect answers coded as 0. Student responses were paired, and the difference between CBCT and AR scores was examined using a paired-sample *t*-test. Data analysis was performed using SPSS at a significant level of $p < 0.05$.

3. Results

3.1. Student Performance in CBCT vs. AR Learning

A total of 43 third-year dental students participated in the study, comprising 18 males (41.9%) and 25 females (58.1%). Students were assessed on their knowledge of root canal anatomy using CBCT images and AR models. The total score for each assessment method ranged from 0 to 18, representing the combined score for the three questions mentioned in the methods.

The results indicated that students scored significantly higher when utilizing the AR model than CBCT images ($p < 0.05$). The mean difference in scores between the two methods was 3.95 points, representing a 37% improvement in performance with the AR model (Figure 3).

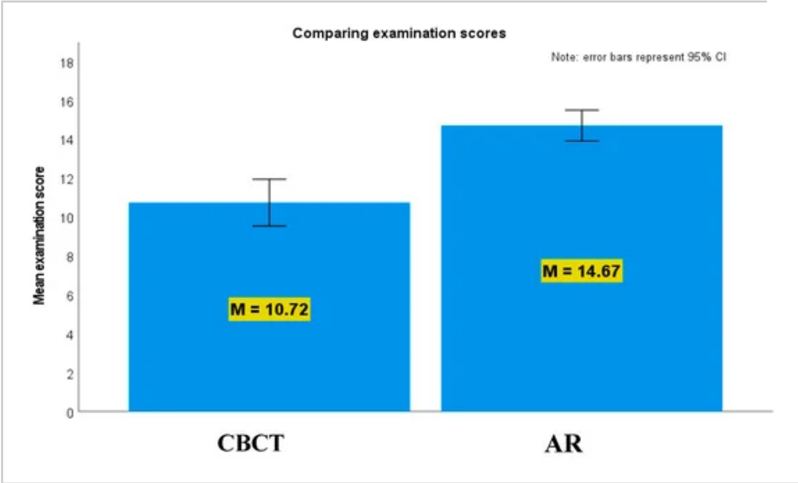

Figure 3. The mean scores of AR and CBCT assessments of 6 teeth were studied. The difference was 3.95 units (statistically significant $p < 0.05$).

Furthermore, a detailed analysis of individual tooth questions revealed statistically significant differences in favor of the AR model for five out of six teeth assessed ($p < 0.05$). These findings are summarized in **Table 1**.

3.2. Gender Differences in CBCT and AR Performance

A mixed-model ANOVA was conducted to examine differences in CBCT and AR scores between male and female participants. The test type (CBCT vs. AR) was included as a within-subjects factor, and gender was included as a between-subjects factor. A significant main effect of test type, $F_{(1,41)} = 39.72$, $p < 0.001$, indicates an overall difference in scores between CBCT and AR. A significant interaction between test type and gender was found, $F_{(1,41)} = 19.60$, $p < 0.001$, suggesting that the difference between CBCT and AR scores varied by gender. Female participants exhibited significantly higher AR scores (M = 15.12, SD = 2.71) compared to CBCT scores (M = 9.08, SD = 2.80), t (41) = 8.42, $p < 0.001$, with a mean difference of 6.04 units (95% CI [4.57, 7.51]). While male participants also showed higher AR scores (M = 14.06, SD = 2.29) compared to CBCT scores (M = 13.00, SD = 4.13), this difference was not statistically significant, t (41) = 1.18, $p = 0.226$. There was no significant main effect of gender on overall test scores, $F_{(1,41)} = 3.71$, $p = 0.061$, indicating no overall difference in mean scores between males and females (**Figure 4**).

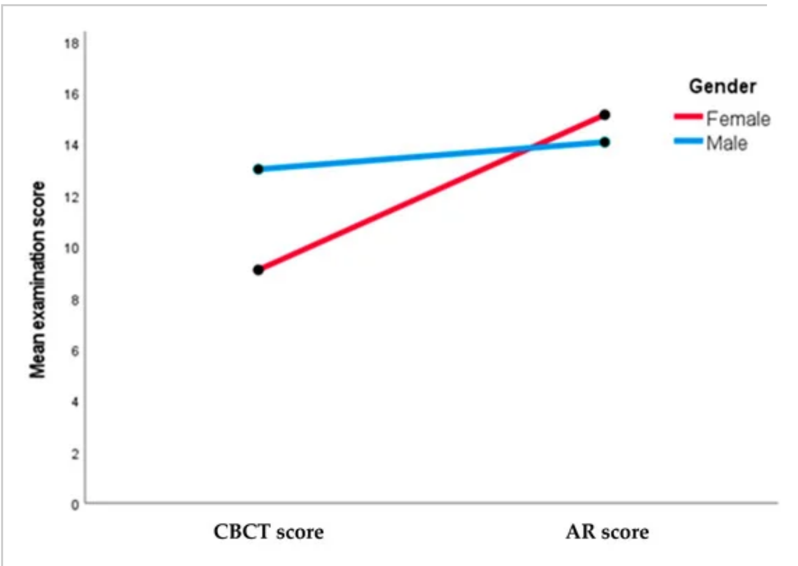

Figure 4. Examination scores for females and males in CBCT and AR assessments.

3.3. Time Efficiency and User Experience with AR and CBCT Learning Modalities

Students spent less time completing AR tasks (M = 4.09, SD = 3.55) compared to CBCT (M = 15.21, SD = 8.01), and the difference was statistically significant ($p < 0.001$). On average, students completed AR tasks faster by 11.12 min (SD = 8.28).

Feedback was received regarding the AR simulation compared to CBCT. The results are summarized in **Table 2**. Most students (93%) indicated that AR stimulation improved comprehension of the root canal anatomy compared to CBCT interpretation. Most respondents (93%) had no problems during the VR simulation, and only three students (7%) experienced some disorientation or sickness.

Table 2. Student Feedback on AR vs. CBCT Simulation. Percentages indicate the proportion of students who selected each response.

4. Discussion

The current investigation tested the null hypothesis and stated that using AR for learning root canal anatomy does not significantly improve students' accuracy in identifying root canal anatomy. CBCT images and AR models of different teeth were used in this study to learn root canal morphology, and a survey questionnaire evaluated the effectiveness of each model. The results revealed that the AR model enhanced students' understanding of root canal morphology. Students showed a significantly improved understanding of root canal morphology across all teeth studied (except for the maxillary second premolar) when using the AR model compared to CBCT (37% increase, $p < 0.05$). The maxillary second premolar had a single canal without branching or merging complexities. It may have limited the observed differences between the two learning modalities for this specific tooth type. Previous investigations indicated that CBCT or VR appeared equal for training dental students to detect all root canal systems [5]. However, Moro et al. recommended the VR modality in medical education, although no significant difference was found between different learning methods [10].

This study demonstrates the potential of AR as a tool for enhancing dental students' comprehension of root canal anatomy. Students displayed a significant increase in accuracy and efficiency when utilizing the AR model compared to CBCT interpretation. One limitation of this study was the sequential design, where CBCT interpretation preceded the AR experience. While a washout period was implemented to minimize knowledge transfer, a learning order effect cannot be entirely ruled out. This effect could give students some pre-existing knowledge that might have aided comprehension of the subsequent AR model depicting the same teeth. Future research could explore randomized controlled trials to strengthen the findings further and address the learning order effect. However, considering that the study design ensured students were not informed about the source of the teeth used in the AR model and the recognized challenges associated with teaching and achieving competency in endodontic skills for dental students [11,12], the current study provides encouraging evidence for incorporating AR as a supplementary learning tool alongside existing methods.

Students spent less time completing the AR observation (M = 4.09, SD = 3.55) than the CBCT interpretation (M = 15.21, SD = 8.01), and the difference was statistically significant. The three-dimensional visualization and manipulation of the AR model led to improved interpretation, better understanding, and faster answering of the survey questions compared to CBCT images. The faster completion of the survey in the AR model could be due to the repetition of the questions. The same questions were answered in the first model tested. Reading the question the second time would be much faster than reading it the first time.

Faculty should choose the teaching and learning method that closely matches the preferred student's learning style, as it has been reported that most students prefer interactive teaching, including the VR model [13,14]. The AR model helped the students to manipulate structural separation and superposition and allowed the user to rotate the tooth model 360°. The present study found that participating students (93%) preferred AR simulation over CBCT images. However, past research has recommended that the VR model should not be used solely in teaching, even if students like it, because they should be trained on the different radiographic imaging modalities utilized in clinical practice and CBCT interpretations [7].

Results herein reported that few students experienced eye fatigue, nausea, and disorientation. These symptoms associated with the VR experience are called VR sickness or cybersickness. This phenomenon is like motion sickness, which occurs due to a disturbance in the perceptual system since the visual stimulation is inconsistent with the vestibular motion sensation [15].

The study employed an immersive metaverse environment requiring a stable Internet connection. While efforts were made to accommodate multiple users, the bandwidth limitations restricted simultaneous participation to four students. Additionally, managing headset battery life necessitated recharging after each use.

5. Conclusions

This study demonstrates the potential of AR as a valuable tool for enhancing dental students' understanding of root canal anatomy. Our findings indicate that dental students who utilized AR technology exhibited significantly improved accuracy and efficiency in identifying root canal structures compared to those who relied solely on CBCT images. The positive feedback from students further supports the notion that AR provides a more engaging and practical learning experience.

While this study provides compelling evidence for the benefits of AR in dental education, further research is warranted to explore its long-term impact on clinical practice. Longitudinal studies are needed to assess whether improved knowledge acquired through AR translates to enhanced clinical skills and patient outcomes. Additionally, investigating the optimal integration of AR into dental curricula and the development of standardized assessment tools for AR-based learning are essential for maximizing its educational potential. By addressing these areas, future research can further solidify the role of AR as a transformative technology in dental education and contribute to the development of more skilled and confident dental practitioners.

Author Contributions

Conceptualization, F.A. (Fahd Alsalleeh) and K.O.; methodology F.A. (Fahd Alsalleeh), R.A.S. and K.O.; software, K.O., F.A. (Fatemah Alrwais) and M.B.; validation, F.A. (Fahd Alsalleeh) and S.A.; formal analysis, F.A. (Fahd Alsalleeh) and S.A.; investigation, K.O., F.A. (Fatemah Alrwais) and M.B.; resources, F.A. (Fahd Alsalleeh); data curation, F.A. (Fatemah Alrwais) and M.B.; writing—original draft preparation, F.A. (Fahd Alsalleeh) and S.A.; writing—review and editing, S.A. and K.O.; supervision, F.A. (Fahd Alsalleeh); funding acquisition, F.A. (Fahd Alsalleeh) All authors have read and agreed to the published version of the manuscript.

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Institutional Review Board Statement

The study was conducted by the Declaration of Helsinki and approved by the Institutional Review Board protocol (IRB No 22-7220) of Health Sciences Colleges Research on Human Subjects College of Medicine King Saud University (22/0944/IRB, 20 November 2022).

Informed Consent Statement

Informed consent was obtained from all subjects involved in the study.

Data Availability Statement

The data of this study are available from the corresponding authors upon reasonable request. The data are not publicly available due to privacy concerns.

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Conflicts of Interest

The authors declare no conflicts of interest. The funders had no role in the study's design; in the collection, analyses, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results.

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