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Virtual reality: an effective tool for teaching root canal anatomy to undergraduate dental students – a preliminary study

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Abstract

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Aim To introduce virtual reality (VR) into the endodontic curriculum for teaching root canal anatomy and to evaluate the effectiveness of this new method on third-year undergraduate students.

Methodology Extracted human teeth were digitized using a CBCT scan and converted into STL files. The corresponding files were either 3D printed or imported into a VR software program. Subsequently, forty-two third-year undergraduate dental students in preclinical training were asked to respond to a questionnaire analysing their ability to detect all the anatomic features of the replica teeth and their comprehension of the underlying root canal anatomy. The investigation was based on three different methods: two-dimensional radiography, CBCT scanning and VR simulation. Data were analysed using McNemar's and binomial test, and the level of significance was set to 0.05 ($P = 0.05$).

Results Students reported that CBCT and VR allowed them to detect all anatomic features more than radiography ($P < 0.001$ – $P = 0.049$). Because it allowed improved comprehension of root canal anatomy, the VR simulation was considered better than CBCT scanning and radiography. Most of the students adapted well to the VR simulation.

Conclusions Dental students greatly appreciated the integration of VR simulation into the endodontic curriculum. From a didactic point of view, VR has considerable advantages over three-dimensional reconstructions and two-dimensional radiographs when teaching root canal anatomy.

Keywords: CBCT, dental students, education, questionnaire, virtual reality, X-ray.

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Introduction

An in-depth knowledge of root canal anatomy is the foundation of successful root canal treatment. According to the Undergraduate Curriculum Guidelines for Endodontology by the European Society of Endodontology (ESE 2013), students should have *knowledge* of dental anatomy to *be competent* in performing good quality root canal treatments, which means, amongst other things, identifying all canals and negotiating them (ESE 2013). Various didactic methods exist to teach root canal anatomy to students to achieve this aim. Dental anatomy is traditionally studied from textbooks presenting clinical photographs, radiographs or schematic drawings – an approach considered to be a passive learning process (Obrez

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et al. 2011). Consequently, students have evaluated this approach as cumbersome and boring (Russell *et al.* 2004). Three-dimensional visualization of different teeth derived from μ-CT (microcomputed tomography) analysis is a valuable addition to an endodontic lecture. Although these scans may help students understand the complexity of dental anatomy, they are still considered a passive approach.

Software programs such as the 3D Tooth Atlas (eHuman, Fremont, CA, USA) are available to provide students with an interactive data set. Students can select from multiple types of tooth anatomy and study them from different directions. Specific tooth structures can be made transparent so that they can see beyond them and even navigate through the root canal (Mowery *et al.* 2010). Thus, the learning process becomes active. Students can use these applications whenever they choose – on and off campus. The acceptance of learning assistance increases, especially during the clinical part of the curriculum when dental students are faced with patient treatment (Wright & Hendricson 2010). Computer-assisted learning (CAL) of dental anatomy has been reported to have results equivalent to those of traditional lectures and to yield benefits in many fields for both dental students and faculty (Bogacki *et al.* 2004, Nicholson *et al.* 2006).

Apart from CAL programs running on personal computers, more sophisticated applications offering virtual reality (VR) have been integrated into university curricula (Buchanan 2004). The term '*virtual reality*' is used for a wide range of different equipment and approaches, and a distinction is typically made between '*virtual reality*' (VR) and '*augmented reality*' (AR). In a VR environment, a computer- and software-supported simulation is so realistic that users can immerse themselves in the VR world. AR, however, is an extension of perceptible reality, whereby additional information, such as texts or virtual objects, can be displayed in the user's field of vision.

Three-dimensional visualized models with haptic feedback in which entire treatment scenarios can be simulated (Dută *et al.* 2011) have been used in dental education. These simulations are of great benefit, especially for training in invasive procedures. This equipment, however, is expensive and thus not yet available for personal use. Nevertheless, because of its highly motivating effect on students, VR is considered to be the next step in higher education (Freina & Ott 2015).

Therefore, the purpose of this preliminary study was to integrate VR into the strategy for teaching root canal anatomy in a CAL approach using computer and software programs that are affordable for dental schools and for individuals. Student feedback on this new method and their ability to detect all anatomic features in comparison with two-dimensional radiographs and cone-beam computed tomography (CBCT) data were evaluated. The null hypothesis stated that no difference would be found between the different methods of enabling dental students to better comprehend root canal anatomy.

Materials and Methods

This study was approved by the Ethics Committee of the University Hospital of Munich under No 19-410 UE and No 19-411 UE.

Sample selection

From a collection of permanent extracted human teeth, one first maxillary molar and one first and second mandibular molar were chosen. The selected teeth were free of caries, restorations, or previous endodontic treatment. According to the system proposed by Ahmed *et al.* (2017), the maxillary molar was classified as $^{3}16\ MB^{2}\ DB^{1}\ P^{1}$, and the mandibular molars were classified as $^{2}46\ M^{2\text{-}1}\ D^{1}$ and $^{2}47\ M^{2}\ D^{1}$.

Digitalization process

A CBCT scan (Carestream 9300; field of view: 5 × 5 × 5 cm; 78 kV, 6.3 mA; 20 s; Carestream, Rochester, NY, USA) of each tooth was conducted with a voxel size of 90 μm. Subsequently, the corresponding DICOM (Digital Imaging and Communications in Medicine) files were imported into the software application *Invesalius for Mac 3.0* (Centre for Information Technology Renato Archer, Amarais, Brazil) to convert the DICOM data into an STL (Standard Tessellation Language) file. These STL files were imported into VR software *VRED 2018* (Autodesk, San Rafael, CA, USA). For visualization of the teeth in virtual reality, a head-mounted display (HTC VIVE; HTC, Taoyuan, Taiwan) was connected to the computer.

3D printing process of the tooth replicas

The STL files of the teeth were imported into the application *Netfabb Standard 2018* (Autodesk) and additively manufactured using the DLP-printer Solflex 350 and the resin V-ee (both VOCO, Cuxhaven, Germany). After the printing process, the support structure was removed, and the replicas were cleaned for two minutes with 96% ethanol in an ultrasonic bath and centrifuged for 5 min at 3500 revolutions per minute (Allegra X-15R; Beckman Coulter Life Science, Brea, CA, USA) to remove unpolymerized resin from the canals (Reymus *et al.* 2019).

Lecture on root canal anatomy

The third-year students ($n = 42$) received a 2-h lecture on dental anatomy with periapical radiographs and images from μCT scan reconstructions covering every tooth type of the permanent dentition. Root canal anatomy was reviewed extensively, including root canal configuration types for every tooth type and anatomical variations. Special focus was placed on the existence of confluence in canals. The classification of Ahmed *et al.* (2017) was presented during the lecture.

Inspection of two-dimensional radiographs

As a first step, the students were given the 3D printed replicas and asked to make a periapical radiograph and complete a questionnaire (Appendix S1). The questionnaire was developed by two senior lecturers specializing in Endodontics and was reviewed by a third senior lecturer to obtain a consensus amongst all three lecturers. The questionnaire asked the student to identify the configuration of the root canals, whether the root canals merged and whether the student could fully comprehend the root canal anatomy on the basis of the radiograph.

CBCT scan inspection

In a second step, students were given videos of a CBCT of the same training teeth in which all slices of the teeth could be inspected in all dimensions. The videos were uploaded on an e-learning platform to enable the students to assess the scan on their own. After interpreting the CBCT scan, the students answered the same questionnaire.

Virtual reality inspection

In the final step, the students viewed the training teeth in a virtual reality environment. Using the software, every tooth was scaled to a size of approximately 70 cm in height. The students could inspect the tooth from all aspects, walk around it, look inside of it or slice the image (Fig. 1). In addition to completing the questionnaire, the students were asked to state which method was most helpful in understanding root canal anatomy, which method was the better didactic tool with which to study dental anatomy in the future and how well they coped with interacting in virtual reality.

Evaluation

In the evaluation of the questionnaire, each question was given one point if the answer (root canal configurations, existence of a merge) was correct and zero points if the answer was incorrect. For the question of whether the students thought they fully understood the anatomy of the tooth based on the method used (radiograph, CBCT, VR), one point was given if they stated yes and zero points if they indicated no.

Data analysis

Data were analysed with statistical software (IBM SPSS Statistics, version 25; IBM Corp, Armonk, NY, USA) using McNemar's and binomial test. An additional statistical analysis (Cronbach alpha test) was carried out to determine the reliability of the responses. The level of significance was set to 0.05 ($P = 0.05$).

Results

All students participated in the investigation (response rate = 100%). McNemar's test revealed significant differences amongst the different methods ($P < 0.001 – P = 0.013$) (Table 1). In most cases, CBCT or VR led to better results than periapical radiography. However, no significant differences were found between CBCT and VR. In terms of better comprehension of root canal anatomy from a didactic point of view, binomial tests revealed that the students preferred CBCT or VR over periapical radiographs ($P < 0.001$) and VR over CBCT ($P < 0.001$; Fig. 2). Problems whilst evaluating the teeth in VR were reported by five students (Fig. 3).

Regarding the students' preferred method of studying dental anatomy in the future, most opted for VR (30), followed by CBCT (10) and periapical radiographs (2). Cronbach's alpha test revealed a value of

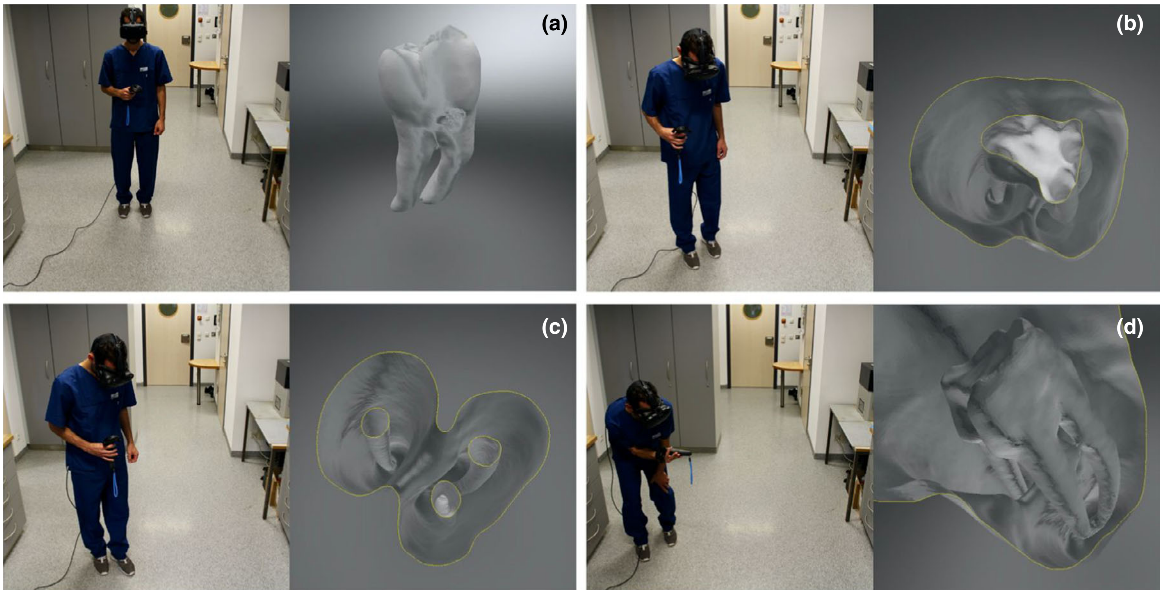

Figure 1 Student interacting in virtual reality with the first mandibular molar: (a) the tooth in overview, (b) looking into pulp chamber, (c) slicing in horizontal plane through the course of the canals and (d) merging of the mesial canals.

Table 1 Descriptive statistics on students' performance to detect the correct root canals configuration (ConX, whereby 'X' stands for tooth) and on students' perception to fully understand the tooth's anatomy (AnaX).

	Con16	Con46	Con47	Ana16	Ana46	Ana47
X-Ray	$0.25 \pm 0.44^{a,b}$	0.73 ± 0.45	$0.58 \pm 0.5^{a,b}$	$0.4 \pm 0.50^{a,b}$	$0.63 \pm 0.49^{a,b}$	$0.48 \pm 0.51^{a,b}$
CBCT	$0.60 \pm 0.50^{a,b}$	0.88 ± 0.34	$0.73 \pm 0.45^{a,b}$	$0.9 \pm 0.30^{a,b}$	$0.95 \pm 0.22^{a,b}$	$0.95 \pm 0.22^{a,b}$
VR	$0.73 \pm 0.45^{a,b}$	0.85 ± 0.36	$0.80 \pm 0.41^{a,b}$	$0.98 \pm 0.16^{a,b}$	$1.00 \pm 0.00^{a,b}$	$0.98 \pm 0.16^{a,b}$

^{a,b}Presents significant differences between methods within one column.

0.718, which indicates good reliability of the questionnaire (Streiner 2003).

Discussion

This investigation evaluated the use of virtual reality for teaching root canal anatomy. The authors are unaware of previous studies on the use of VR in the teaching of dental anatomy, although training with three-dimensional visualization on digital haptic models is already widely in use (Buchanan 2001).

This investigation tested a cost-effective way of integrating virtual reality into the endodontic curriculum. By using an open-source software solution such as *Invesalius* (invesalius.github.io), *3DSlicer* (www.slicer.org) or *ITK-Snap* (www.itksnap.org), DICOM data of extracted human teeth can easily be converted into STL files. The files can be viewed with the help of VR software applications such as the one described, which is free of charge for educational purposes using a head-mounted display. The cost of these devices has dramatically decreased in the past few years (Attaran 2017). Nevertheless, introducing this new technology would increase initial investment costs for dental schools in comparison with using three-dimensional visualizations derived from online sources.

This investigation found that CBCT and VR appear to be equally suitable for training a student to detect all root canals, to determine whether emerging canals are present and to understand the anatomy of the tooth. Two-dimensional radiographs, however, were found to be inferior in these respects. The advantage of three-dimensional over two-dimensional visualization was not unexpected. However, the study suggests that using VR is not necessarily an improvement compared to CBCT when identifying tooth anatomy.

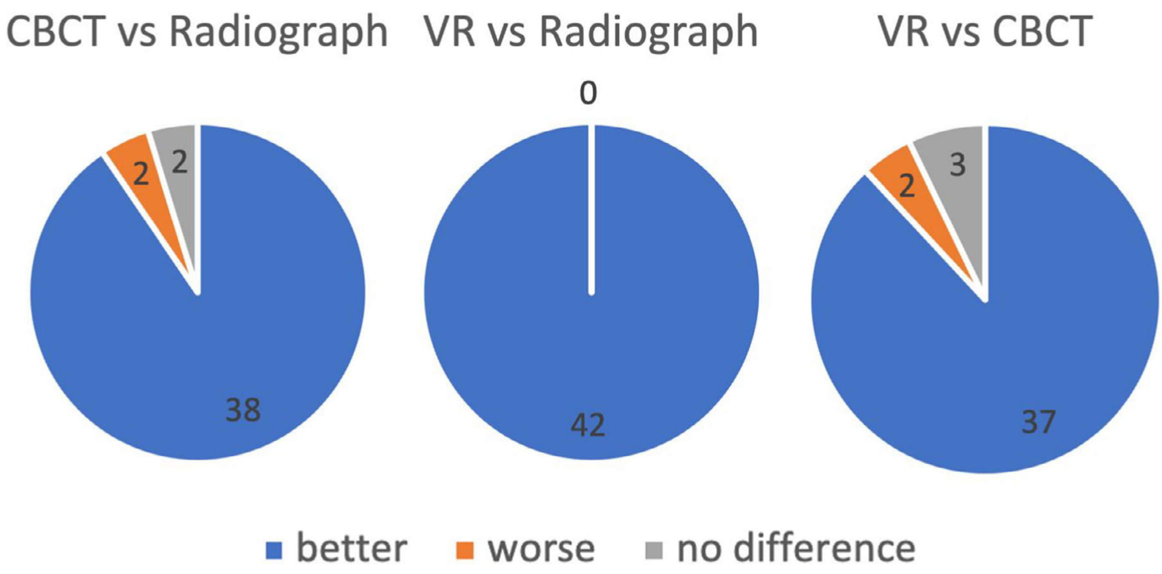

Figure 2 Student comprehension of tooth anatomy (X was better/worse/the same than Y in comprehending tooth anatomy) in total numbers (for all comparisons significant differences could be detected between the different methods, $P < 0.001$).

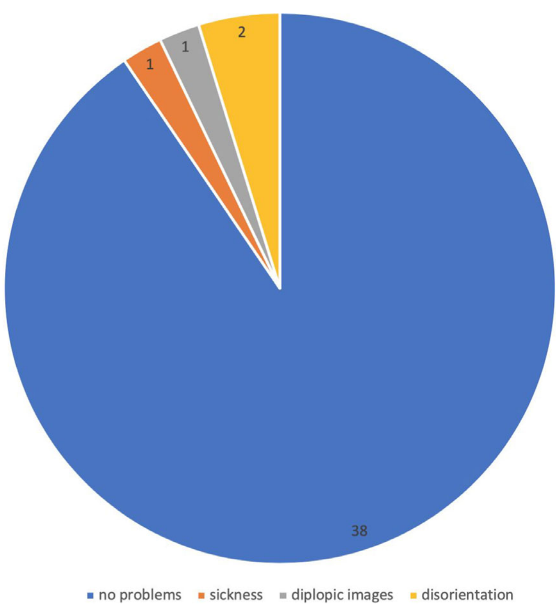

Figure 3 Reported problems when interacting in virtual reality.

However, clinical studies are needed to confirm this hypothesis.

Limitations of the investigation included the fact that the order of the methods was not randomized – all started with two-dimensional radiographs, followed by CBCT and then VR. However, the techniques were directly compared with each other to evaluate the students´ preference for one technique over the others. Care was taken to ensure that the students filled out the questionnaire step by step after the observation of each technique. Consequently, the students' performance in detecting root canals in accordance with each technique could be evaluated. Nevertheless, by evaluating one method, they might have benefited from the knowledge gained by the previous method. However, the sequence of two-dimensional radiographs followed by three-dimensional scans represented the most likely clinical situation.

The focus of the present investigation was to obtain the students' evaluations of the use of virtual reality in teaching dental anatomy and to compare this new method with conventional methods. Students preferred VR over CBCT from a didactic point of view. They stated that they gained a better understanding of the tooth's anatomy when using virtual reality. This may be because of the unique possibility of interacting with the object by walking around the virtual tooth, looking inside it and slicing through it. This preliminary study investigated the feasibility of VR in teaching root canal anatomy. For this purpose, only a selection of possible anatomic features in only a limited number of samples was designed, which is a limitation of the current study. The focus for third-year students in their last preclinical course was the anatomical features of a separate MB2 canal in maxillary molars and the confluence of two mesial canals in mandibular molars. After the feasibility had been determined by this preliminary study, more models with specific anatomic features can be introduced to focus on different aspects of root canal anatomy.

The classification of root canal anatomy proposed by Ahmed *et al.* (2017) was preferred because it elegantly describes the three-dimensional complexity of the root canal system. Recently, the new system was evaluated by dental students in Malaysia (Ahmed *et al.* 2020) and was reported to be highly beneficial for their understanding of root canal anatomy. These findings are promising and need to be further evaluated, especially with the introduction of VR in endodontic education. However, this preliminary study did not focus on a comparison of the acceptance of different root canal anatomy classifications but raised the awareness of inexperienced students to the existence and prevalence of confluent canals and their clinical implications, since they present a major risk for iatrogenic complications during student treatment, for example file separation.

Commercial software developers such as *eHuman* (ehuman.com) have recently promoted smartphone applications that offer a virtual reality platform for teaching dental anatomy. These applications, however, have more limitations than the technique used in the present investigation. The technology of the *eHuman 3D tooth* atlas permits observation and inspection of a tooth in three dimensions but is more like watching a three-dimensional movie than actively interacting with the object. A few students reported problems interacting with the teeth in the virtual reality environment, possibly because this was their first experience with VR. It can be assumed that they will become accustomed to the experience.

Several VR projects have been described in medical education (Barsom *et al.* 2016), typically playing a positive role in the learning process. For teaching anatomy, the VR approach was highly appreciated by students and residents (Falah *et al.* 2014, Moro *et al.* 2017). Yeo *et al.* (2011) stated that residents who had received lumbar puncture training with VR outperformed their colleagues in this procedure. The positive didactic effect of using VR in teaching root canal anatomy is consistent with another study in which students were faced with simulated head trauma (Gutierrez *et al.* 2007).

The present investigation focused on the evaluation of students' attitudes towards introducing VR into the endodontic curriculum. Further research should focus on the added value generated by this method compared with conventional methods. A randomized controlled trial of two groups of students, one training with VR and one with conventional methods, tested in a final examination on dental anatomy might be a suitable approach for this purpose. In a further step, clinical performance could be compared after the students experienced different training methods.

Although the results presented in this study favour the use of three-dimensional imaging over conventional radiographs from a didactic point of view, one must emphasize that such an approach must not prohibit the inclusion of interpreting two-dimensional radiographs from the university curriculum. Conventional radiographs are still the most frequently used initial method for diagnosing periapical pathosis. Consequently, dental students must learn to interpret such imaging astutely to provide the best care and treatment possible.

Conclusion

This investigation revealed the positive attitude of dental students towards teaching dental anatomy using virtual reality. CBCT and VR had comparable results in terms of the students' ability to detect all anatomic features. The majority of the participating students had no problems.

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Conflict of interest

The authors have stated explicitly that there are no conflicts of interest in connection with this article.

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Supporting Information

Additional Supporting Information may be found in the online version of this article:

Appendix S1. Questionnaire.