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STUDENT LEARNING OF HEAD AND NECK ANATOMY USING CONE BEAM COMPUTED TOMOGRAPHY AND IMMERSIVE VIRTUAL REALITY

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Abstract

The purpose of this study was to evaluate the efficacy of student learning of anatomy and 3D imaging concepts using Cone Beam Computed Tomography (CBCT) and immersive virtual reality (VR) technology. Ninety (n=90) first year dental students with no previous experience in 3D imaging were recruited. All participants completed a 10-item, multiple-choice questionnaire (MCQ) and a pre-survey prior to the educational intervention. Following a brief video orientation on CBCT and anatomy, each participant underwent a one-on-one educational intervention using immersive VR with calibrated instructors to identify head and neck anatomic structures using a VR/CBCT educational tool. Immediately following the intervention, all participants completed a post-survey, a second MCQ, NASA Task Load Index and Presence questionnaires. Participants completed a third MCQ two weeks following the intervention. Analysis of objective measures of performance on MCQ's ($p<0.05$) and subjective data from the questionnaires was completed. The students doubled their mean test scores 2.45±1.274 to 5.99±1.576 on MCQ's immediately following the educational intervention ($p<0.05$). The significant increase in the MCQ test scores was maintain after 2 weeks, 5.73±1.721 ($p<0.05$). There were no gender differences in student test performance. Students rated the immersive VR/CBCT educational intervention experience highly for control, sensory and realism factors with minimal distraction and frustration factors. Results from this study show that immersive VR/CBCT educational intervention improved test performance and contributed to information recall in students. Further benefits reported by participants include the sense of presence and increased engagement using immersive VR.

Keywords: Immersive Virtual Reality, Head and Neck Anatomy, Cone Beam Computed Tomography

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Introduction

Anatomy education serves to prepare dental students to improve understanding of the development of the craniofacial complex and assist in clinical training and practice.[1] Due to technological advancements in imaging and computer graphics, 3D visualization methods including cone beam computed tomography (CBCT) are currently being used to help improve students' understanding of anatomy.[2,3] Although cadaver dissection is the standard in learning anatomy, studies have shown that students who used 3D imaging modalities in addition to anatomy consistently performed better on objective knowledge measures such as test scores.[4,5] Supplementing a traditional gross anatomy course with brief radiology-anatomy correlation sessions using radiographs, computed tomography (CT) scans, ultrasound, and magnetic resonance imaging (MRI) had a positive effect on student performance and long-term retention.[6] Despite the availability and utility of CBCT imaging in dentistry, dental education on 3D imaging modality and interpretation appears to be lagging worldwide.[7-9]

CBCT became instrumental in the education and practice of dentistry in a variety of disciplines since the late 1990's.[10-12] One downside of 3D imaging modalities such as CBCT is that they are a two-dimensional (2D) reconstruction of a three-dimensional structure using 2D computer monitors, keyboard and mouse. Extended reality (XR) is a term that is used to describe immersive technologies that can combine physical and virtual environments. Immersive Virtual Reality (VR) is an example of XR.VR offers an experience where participants can interact in an entirely computer generated virtual 3D environment with an intuitive user interface. An immersive VR workstation or hardware includes a computer with sufficient processing power and graphics capability to support a VR head mounted device and hand controllers. There are various custom or commercial software that are available and can be used for various applications.[13] VR has been used to educate students on a variety of

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subjects in higher education.[14] Fully immersive VR technologies with head mounted display units have also been used in medical education for anatomy.[15] Additionally, there are immersive VR simulations for many medical applications including tumor resection, vascular lesion surgical intervention, endoscopy, pedicle screw placement, bronchoscopy and soft skills to help train surgeons for patient care.[16-22]

In dental education, immersive VR has been shown to be as effective as conventional learning methods which can improve student performance in orthognathic surgical prediction and delivery of injections with increase in learner satisfaction.[23-30] Additionally, there may be added benefits for student learning of anatomy and 3D imaging and radiology concepts by combining head and neck anatomy, CBCT images and immersive VR technology to improve the educational experience and knowledge retention for dental students. When Radianti et al. conducted a systematic review regarding usage of VR in higher education, they found that evaluation of VR applications have primarily focused on usability of the VR applications instead of learning outcomes.[14] VR-based learning and pedagogical benefits of XR in dental education should be investigated. The specific aims of this study are to assess first year dental students' experience and outcomes of learning head and neck anatomy and 3D imaging concepts with CBCT images using immersive virtual reality.

Materials and Methods

The study was considered exempt from Internal Review Board oversight at the University of Michigan (HUM00213294).

First year dental students (n = 90) who did not have any previous experience with 3D imaging concepts or evaluating CBCT's were recruited. The participants had completed a head and neck gross anatomy course with cadaveric dissections prior to participating in the study. The subjects completed a pre-survey consisting of age, gender and video gaming

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experience and a 10-item multiple choice question (MCQ) test on 3D imaging concepts and anatomical landmark identification one week before the VR/CBCT educational intervention. A typical MCQ item is shown in Fig 1.

The educational intervention included 3 short videos on basic 3D imaging concepts (duration: 6 min 32 sec), radiographic anatomy using CBCT (duration: 6 min 26 sec) and software and hardware features (10 min 50 sec) of the Immersive View VR software (Immersive Touch Inc., Chicago, IL) and the Rift head mounted device and Touch controllers (Meta, Menlo Park, CA). Following the orientation videos, participants underwent a thirty-minute one-on-one learning intervention using VR/CBCT educational tool with a trained and calibrated instructor. All 5 instructors followed a script to standardize the interactions between the instructor and student. Participants were trained to view CBCT image slices in any plane; sagittal, coronal, axial, or oblique planes, while simultaneously overlaying the CBCT images with the 3D model of the skull within the VR environment. (Fig. 2) When the participants were comfortable visualizing and manipulating the images, they were instructed to navigate in all planes, locate and identify 30 anatomic landmarks from the CBCT images using the VR/CBCT educational tool. The radiographic identification queries included: nasal septum, anterior nasal spine, incisive canal, maxillary sinus, nasal turbinates, pterygoid plates, mandibular foramen, sphenoid sinus, hyoid bone, epiglottis, greater palatine foramen, external auditory meatus, coronoid process, cervical vertebrae, hard and soft palates, clivus as well as other head and neck structures. The participants received immediate feedback on whether they identified the radiographic anatomy and, if needed, correction of the anatomic radiographic landmarks and structures from the instructor was given to the student. Following the educational intervention participants completed a post-survey on their experiences, the Presence Questionnaire (Witmer and Singer, 1998) which consisted of 23 questions on a 1-10 Likert scale, the NASA Task Load Index (Hart and Staveland, 1988) which had 6 questions

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and used a Likert scale of 1-20, and a 2nd 10 item MCQ test.[31, 32] Two weeks after the educational intervention, participants took a 3rd MCQ test. Three MCQ tests consisted of unique questions for each of the three time points, pre-intervention (T1), immediate post-intervention (T2), and two weeks post-intervention (T3). Each MCQ examination was calibrated to have similar difficulty level.

Statistical analysis was completed using SPSS Version 28.0.0 (IBM, Armonk, NY). Descriptive statistics were performed for responses from the Presence and NASA TLX questionnaires as well as mean age, gender, and video game experience from the pre-survey. The results of the MCQ tests were evaluated for normality using Shapiro-Wilk test ($p<0.05$). Kruskal-Wallis test was used to determine significant differences for MCQ tests for T1, T2 and T3 ($p<0.05$). Post hoc Mann Whitney test was used to determine significant differences between MCQ tests at each time point ($p<0.05$). Cohen's d was used to determine the effect size of the intervention. Post-hoc sample size calculation was performed using statistical power of 90% with an alpha value of 0.01. Qualitative responses to the free response post-survey questions were coded for common themes by one of the investigators and corroborated by a second investigator. Any disagreement was resolved after discussion.

Results

Subjects

The sample consisted of 90 first year dental students, 50 females and 40 males, with a mean age of 22.9 ± 2.74 years. The majority of the participants had experience in playing video games (73%), however, most of these students reported playing rarely (39%) or occasionally (20%).

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Multiple Choice Question Test (T1, T2, T3)

For the 10 item MCQ's, the participants correctly answered 2.45 ± 1.274 at T1 (Pre-Intervention), 5.99 ± 1.576 at T2 (Immediate Post-Intervention), and 5.73 ± 1.721 at T3 (2 Week Post-Intervention). (Fig. 3) The Shapiro-Wilk test determined that the MCQ test scores for the three time points, pre-test (T1), immediate post-test (T2), and two-week retention test (T3), were non-parametric. Kruskal-Wallis test followed by Post hoc Mann-Whitney test indicated that there was a significant difference and improvement between T1 and T2 as well as T1 and T3 MCQ test scores ($p<0.05$). The effect size of the intervention was very large immediately (2.45) and 2 weeks (2.15) after the intervention. There was no significant difference in MCQ test scores between T2 and T3. There were no significant differences in MCQ test performance at T1, T2 and T3 between males and females ($p<0.05$).

NASA Task Load Index

The NASA TLX indicate participants' subjective workload assessment for the VR/CBCT educational intervention was very high success in performance of the task with medium mental effort, low physical effort, minimal time pressure and very low frustration level. (Table 1)

Presence Questionnaire

Overall, participants rated their subjective experience of presence using the VR/CBCT tool as high (>8 on a 10 point scale) for control factors, realism factors and sensory factors and low for distraction factors. (Table 2) Highest scores (>9 on a 10 point scale) were given for the ability to examine objects closely and from multiple viewpoints.

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Post-survey Qualitative Data Analysis

Post survey comments indicate that the students were very engaged with the VR/CBCT educational tool. All of the 90 participant comments (100%) were positive for the question "How engaged were you with this technique?" Participants cited high levels of interactivity and engagement. Students also felt that they learned "a lot" (n=67, 74%) and that the visualization and manipulation features of the VR/CBCT tool helped them to better understand anatomy. When asked what they disliked, many responded "nothing" (n=37, 41%), indicating a positive experience. Other responses indicated difficulty with things being blurry (n=9, 10%), dizzy/disorienting (n = 12, 13%) and that there was a learning curve getting use to the controllers (n =12, 13%).

Discussion

Human anatomy, with a focus on the head and neck, is a vital component of dental education. Studies have shown enhanced visualization with high quality 3D imaging such as CBCT combined with cadaveric dissection may facilitate long-term information recall in students.[4-6] Moreover, use of virtual learning environments (VLE) and the pedagogical benefits of this new teaching methodology are being investigated.[33] This study aimed to assess user experience and outcomes of student learning of head and neck anatomy, 3D imaging concepts and CBCT image interpretation with immersive virtual reality using subjective and objective measures to better understand the pedagogy of VR learning systems. The VR software that was used in this study is a commercially available and FDA approved Class II medical device/software named Immersive View (Immersive Touch Inc., Chicago Il). Immersive View VR software allows for viewing 3D images, such as CBCT's, as rendered surface models with fidelity, color and texture. It has several features including manipulation, annotation, measurement and cut planes. The cut planes allows for

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superimposition of the 3D rendered surface models with 2D image slices so that gross anatomy and radiographic anatomy can be simultaneously visualized and manipulated. (Fig. 2)

Dalgarno and Lee identified that in order for VLE to be effective it must have several factors including representational fidelity, immediacy of control and presence.[34] Representational fidelity refers to the resolution and quality of the virtual reality environment. This may include the quality of the 3D representations with realistic textures or how objects move in space in a realistic fashion with smooth frame rates. Even in a virtual environment, objects must move according to logical patterns in order for the user to accept them and feel immersed in the experience. Immediacy of control describes the direct correlation between user input and subsequent effect on the virtual environment. Eliminating lag time between the user's input and any response in the virtual environment helps to maintain an immersive experience for the user. Though the terms "immersion" and "presence" are quite similar, Dalgarno and Lee define immersion as the objective aspects of the virtual environment such as the visual or audio aspects of the experience. Presence combines both the objective characteristics of the virtual environment as well as the user's subjective experience. A virtual reality environment which is responsive, consistent and has high fidelity allows a user to feel present within the environment even though one is physically situated in another.

The Presence questionnaire and the NASA TLX were used in this study because they are validated subjective assessment of presence and workload, respectively.[30,31] The results from the Presence questionnaire demonstrate that the students experienced high levels of control, sensory and realism while using the VR/CBCT tool. The students also had low distraction factors which are noted by minimum delay between their action and the expected outcome, control mechanisms and visual display that did not interfere or distract them from

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the required activities of navigating through the various image planes and identifying anatomical structures and landmarks. One aspect that is unique to learning in virtual reality is the learner interaction where the learner is able to control the point of view, manipulate objects, and navigate a virtual environment. More control of the virtual environment and sensory factors has been correlated to more presence.[30] In this study, the participants gave the highest rating, >9 on a 10 point scale, for sensory factors of examining objects and from multiple viewpoints in the Presence questionnaire.

The NASA TLX is a validated subjective workload assessment which takes into account objective task demands and each individual's response to them.[31] The students felt that they were able to successfully perform their task of navigating through CBCT images overlaid with the skull to identify radiographic anatomical structures. The students felt that the task took moderate mental effort and very low to low physical effort. Students thought that the learning intervention was at a leisurely pace and did not feel time pressure for the rate at which the task elements occurred even though the practical part of the educational intervention consisted of training, navigating, locating and identifying thirty (30) anatomical structures using multiple planes in under 30 minutes. When students were asked, "How insecure, discouraged, irritated, stressed, and annoyed were you?", they responded with very low frustration level (2.5 on a 20 point scale).

Dalgarno and Lee also outline several learning affordances which VR may add to learner's experiences.[34] First, VR tasks can aid in the development of spatial awareness and knowledge. Second, VR can be used to simulate tasks which would be impractical or impossible to replicate in the real world. Third, VR provides a very personalized learning experience which may allow users to detach themselves from the outside world leading to increased intrinsic engagement and motivation. Finally, due to the sensory richness of the VR experience there may be improved transfer of knowledge and skills through contextualizing

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learning. These learning affordances are demonstrated when evaluating the results of the objective measures of the MCQ test scores as well as the qualitative free responses of the participants.

Student performance on MCQ tests before and after the VR/CBCT educational intervention significantly improved their test scores in 3D concepts and identification of CBCT anatomical structures by 100%. This improvement was sustained 2 weeks after the intervention, demonstrating retention of the newly acquired knowledge. Gender differences in student performance was not observed. According to Cohen, the effect of an educational intervention is considered large when >0.8.[35] The effect size of the VR/CBCT educational intervention was very large immediately (2.45) and 2 weeks (2.15) after the intervention. This study sample included 90 first year dental students. Given the very large effect size of the intervention, future similar studies should seek to have a minimum sample size of 7 subjects for sufficient power (90%, $p<0.01$).

Qualitative analysis using coding of the free responses from the students included common themes such as; “very engaged”, learned “a lot”, “visualize”, “contextualize”, “movement”, “understanding”, “interactive”, and “hands-on”. Participants’ free response comments echo the results from the subjective (Presence questionnaire and NASA TLX) and objective data (performance on MCQ tests) supporting VR based learning as an active and constructive process where the learning is student-centered.

The VR educational intervention in this study was only 30 minutes in duration, longer sessions or multiple sessions accompanied with testing at periodic intervals may improve knowledge transfer, recall and retention.[36] A future study that compares student learning outcomes using 2D multiplanar orthogonal views and the VR educational intervention is planned. It would also be interesting to evaluate the impact of the VR educational

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intervention in student understanding and interpretation of other radiographic images, such as panoramic radiographs or tomograms, as well as in direct patient care.

Conclusion

Extended reality (XR) clinical and educational tools with improved representational fidelity, natural user interface and pedagogical benefits are being developed. This study demonstrated significant improvement in dental student knowledge in 3D imaging concepts and head and neck anatomy using an immersive virtual reality educational intervention. This study also showed additional benefits such as increased student engagement in learning, positive experience and the sense of presence with VR-based learning.

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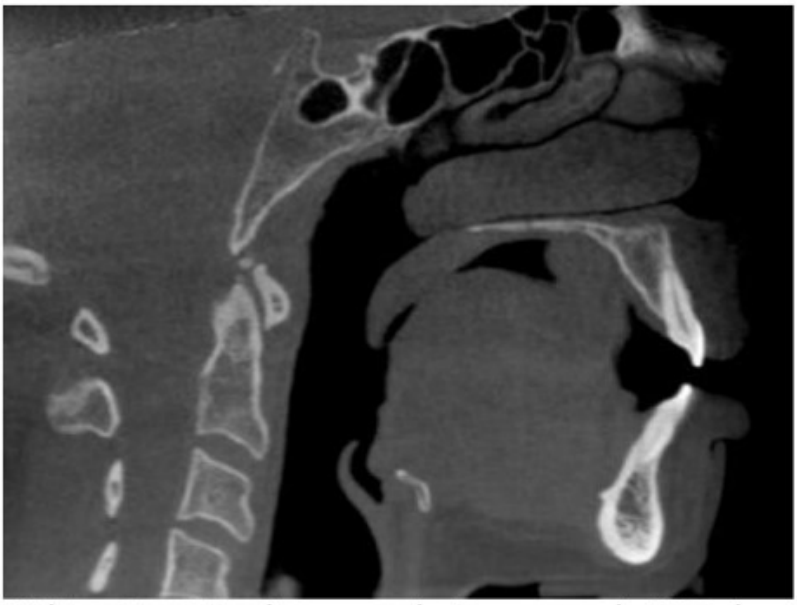
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Figure Legend

Q3



Which of the following anatomical structures is **NOT** visualized in this CBCT image?

- ○ Hyoid Bone
- ○ Maxillary Sinus
- ○ Sella Turcica
- ○ Cervical Spine
- ○ Inferior Nasal Turbinate

Figure 1: An example of the multiple choice question test item.

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Figure 2: Image of a student wearing the Rift head mounted device and navigating Immersive View software with 3D model of the head overlaid with CBCT image in the axial plane using Touch controllers.

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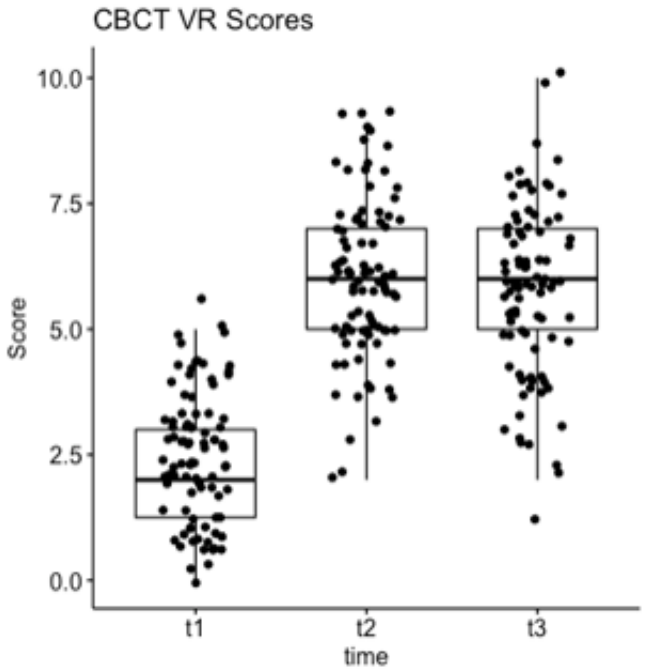


Figure 3: The results of 10 item multiple choice question tests at T1 (Pre-Intervention), T2 (Immediate Post-Intervention) and T3 (2 Week Post-Intervention). There was a significant difference in T1 vs. T2 and T1 vs. T3 ($p<0.05$). There was no significance difference between T2 and T3.

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Table 1 NASA Task Load Index

Item	Mean	SD	Conclusion
How mentally demanding was the task?	7.1	4.70	Medium mental effort
How physically demanding was the task?	3.8	3.34	Low physical effort
How hurried or rushed was the pace of the task?	3.7	3.85	Slow, leisurely rate
How successful were you in the task?	15.1	3.93	Very high success
How hard did you have to work to accomplish your level of performance?	7.7	4.44	Medium effort
How insecure, discouraged, irritated, stressed, and annoyed were you?	2.5	3.38	Very low frustration

Scale 1-20: 0-3 = very low, 15-20 = very high

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Table 2 Presence Questionnaire Analysis

Item	Mean	SD	Factor
How much were you able to control events?	8.6	1.47	CF
How responsive was the environment to actions that you initiated?	8.6	1.49	CF
How natural did your interactions with the environment seem?	7.9	1.74	CF
How much did the visual aspects of the environment involve you?	8.1	1.84	SF
How natural was the mechanism which controlled movement through the environment?	8.0	1.67	CF
How aware were you of events occurring in the real world around you?	4.9	2.91	DF
How aware were you of your display and control devices?	8.0	1.59	DF
How compelling was your sense of objects moving through space?	8.2	1.69	SF
How much did your experiences in the virtual environment seem consistent with your real-world experiences?	7.0	2.12	RF, CF
Were you able to anticipate what would happen next in response to the actions that you performed?	8.3	1.54	CF
How completely were you able to actively survey or search the environment using vision?	8.5	1.36	RF,CF,SF
How compelling was your sense of moving around inside the virtual environment?	8.4	1.44	SF

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How closely were you able to examine objects?	9.2	1.07	SF
How well could you examine objects from multiple viewpoints?	9.1	1.14	SF
How well could you move or manipulate objects in the virtual environment?	8.4	1.36	CF
To what degree did you feel confused or disoriented at the beginning of breaks or at the end of the experimental session?	3.3	2.87	RF
How involved were you in the virtual environment experience?	8.9	1.10	CF
How distracting was the control mechanism?	2.3	1.98	DF
How much delay did you experience between your actions and expected outcomes?	1.9	2.19	CF
How quickly did you adjust to the virtual environment experience?	8.1	1.64	CF
How proficient in moving and interacting with the virtual environment did you feel at the end of the experience?	8.3	1.39	CF
How much did the visual display quality interfere or distract you from performing assigned tasks or required activities?	2.6	2.98	DF
Did you learn new techniques that enabled you to improve your performance?	8.6	1.60	CF

Scale 0-10; 0-1 = not at all, 5 = somewhat, 8-10 = completely

Factors for presence: Control (CF), Sensory (SF), Distraction (DF), Realism (RF)

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