Haptics Vs Typodonts for Crown Preparation in Undergraduate Dental Student Education

ABSTRACT

Objectives: This study aims to compare students' subjective perceptions and objective results by comparing two methods of crown preparation: typodonts and haptics. Materials and methods: Fifty-four second-year students were given instructions on crown preparation for the upper right second premolar. First on typodonts and then with haptics. They were given five minutes to familiarize with the artificial environment and then thirty minutes for the actual preparation. Finally, they completed a questionnaire about their experience. Their preparations were objectively compared by measuring the angle of total occlusal convergence-TOC on the typodonts and with haptics. Results: Students reported that haptics can enhance the learning process and that they would use them for skill training in the future. Overall, their experience was rated as positive. The TOC of teeth prepared with haptics was significantly higher than those prepared with typodonts, but all values were within the acceptable range. Conclusion: Although students did not prefer haptics to typodonts, haptics appear to be a powerful tool in the educational process because it can be a complementary option to traditional methods at the preclinical level.

INTRODUCTION

In the late 1970s, there was a tendency in both computer games and flight simulations to augment virtual reality (VR) with haptics to increase realism and emphasize sensory feedback.[1] Virtual reality simulators or haptics were developed for use in dentistry in the late 1990s, although, they were employed as virtual reality simulators in dental schools a decade later.[1] There are two different forms of simulators: virtual reality (VR), in which the user is fully immersed in an environment through a head-mounted display with no contact with the natural environment, and augmented reality (AR), in which the user wears special smart glasses that overlay digital information with the physical surroundings.[2]

These devices are used in dentistry mainly for restorative dentistry (31.5%), prosthetic dentistry (17.4%), maxillofacial surgery (12.3%), and to a lesser extent for other purposes, such as endodontics (8.2%) and implantology (6.8%).[3] Evidently, such a device is required to enhance traditional teaching methods for students and provide further education for qualified dentists in areas outside the standard dental education. Regarding the latter, a virtual environment would be crucial before venturing into the clinical practice, e.g., implant placement, maxillofacial surgery or apicoectomy.

Keywords

Prosthodontics
Haptics
Crown Preparation
Dental Simulators
Simodont

Authors

Christina Hadjichristou *
(Lecturer in Prosthodontics)

Dimitrios Symeonidis *
(Undergraduate Student)

Evangelia Dimitriadou *
(Undergraduate Student)

Address for Correspondence

Christina Hadjichristou *

Email: c.hadjichristou@euc.ac.cy

* *School of Dentistry, European University Cyprus, Nicosia, Cyprus*

Received: 23.10.2023
Accepted: 08.12.2023

doi: 10.1922/EJPRD_2647Hadjichristou08

ejprd.org - Published by Dennis Barber Journals. Copyright ©2024 by Dennis Barber Ltd. All rights reserved.

For fixed prosthodontics training, dental schools traditionally use typodonts with acrylic teeth that are freestanding or mounted on phantom heads to train dental students in tooth preparation. This educational process requires close supervision of students by trained professionals and an annual supply of materials to replace the inventory of handpieces, diamond drills, mirrors, periodontal probes, silicone putty, and acrylic teeth, as well as personal protective materials, such as gloves, eye protection, and any other relevant equipment.

Haptics, nevertheless, appear to be very attractive in dentistry for many reasons. Firstly, these devices do not require the purchase or renewal of materials/equipment; therefore, can be proven to be cost-efficient for dental schools. They do not require constant monitoring by personnel but rather provide reproducible feedback for the user, allowing repetition of the particular exercise. Moreover, haptic simulators offer different case scenarios for rehabilitation with unlimited hours of practice.[1,2] Most importantly, the treatment poses no physical risk to either the patient or the student, and the cross-infection risk is eliminated, primarily because there is no water/suction used. These factors ensure a smooth transition from the preclinical to the clinical setting.[1–3]

The introduction of haptics in dentistry has been gradual over the years starting in 2004 with various systems such as DentSimTM, VOXEL-MAN, Simodont® Dental Trainer, PerioSim®, Virsteasy Dental, IDEATM, SimImplanto, and Leonardo.[4] Of these systems, the Simodont® is the most commonly used for prosthetic purposes. The user can choose between different dental procedures via the settings on AR. The device is connected to the teacher's station, where the instructor can monitor the students' work in real-time. A second option is to save the students' work for later review and evaluation.

For the objectives of this study, second-year dental students were asked to use the haptic devices after they had completed their training on traditional typodonts. The aim of this study was twofold. One part consisted of investigating students' preferences between the two learning methods (traditional training by preparing teeth on typodonts vs. preparing teeth on haptics). The results were to be evaluated subjectively through questionnaires to be filled in by the students after the completion of the exercises. The second aspect would be the objective evaluation of the resulting preparations with regard to the buccolingual and mesiodistal total occlusal convergence (TOC) angles. The hypothesis is that the students' preparations would not differ significantly in terms of TOC angles after the two methods. The second hypothesis would be that students' preferences would not differ significantly between the two methods.

MATERIALS AND METHODS

Participants and Setting: 54 second-year dental students participated in this experimental design. The students had used a handpiece for three fixed, full-coverage preparations on typodonts during the same semester, but almost none of the students had used a dental simulator in the past. After completing the mandatory preparations on typodonts (#36,11,15), they were asked to voluntarily participate in this experimental protocol to gain experience with crown preparations in an AR environment. Fifty-four students expressed interest in participating. They were assured that their involvement in this study would not negatively affect their grades. Following their use of the haptics, participants responded to a 23-item questionnaire asking them to indicate their demographic data and their preferences regarding the haptics utilization. Furthermore, students were requested to share two images of their corresponding preparation on the typodonts, one from the mesial side and one from the buccal side, which would allow measurement of buccolingual TOC and mesiodistal TOC, respectively, to compare these angles with those that would result from the preparation with the haptics *(Figure 1)*.

Study design: The typodont preparation of the upper second molar (#15) is a part of the laboratory curriculum of 2nd year dental students. The students were granted 2 sessions of 1 hour and 40 minutes for this preparation which included a short instructive lecture, crown preparation assessment (grading) and station rearrangement. Regarding the crown preparation protocol, the preparation of the occlusal surface was first in sequence, followed by the preparation of the axial surfaces (palatal-buccal). A bevel was placed on the palatal wall. Finally, the palatal surface was connected to the buccal by the interproximal surface preparation. The preparation

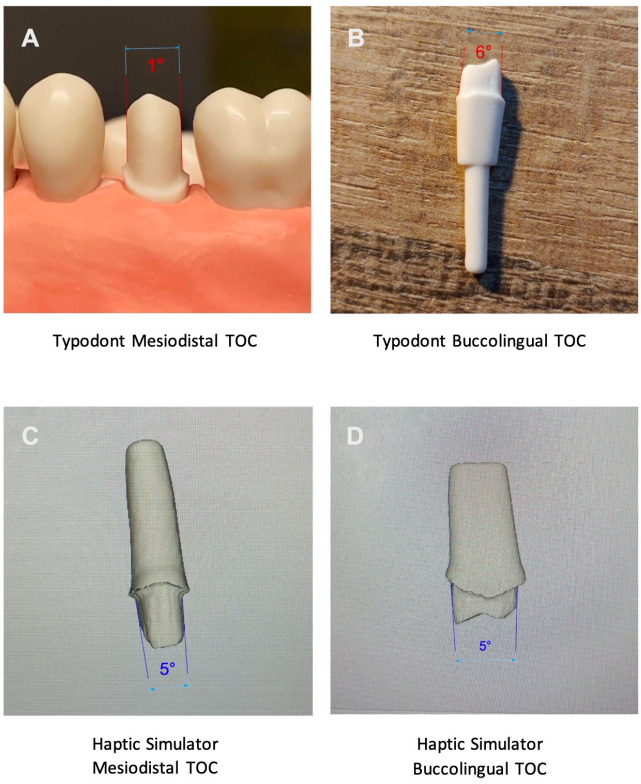

Figure 1: TOC Measurement Demonstration using the ArchiCAD Software, (A,B): Images retrieved from typodont preparations, (C,D): Images of preparations using haptic simulators.

ejprd.org - Published by Dennis Barber Journals. Copyright ©2024 by Dennis Barber Ltd. All rights reserved.

depth was set at 1 mm on each surface, 1.5 mm in the bevel area, and 0.5 mm in the interproximal area. The proposed occlusal convergence of the opposite axial wall was set at 6 degrees, guided by the use of a cylidroconical bur. Upon completing this task, students were provided with example images and requested to photograph their tooth preparation as suggested by the examples given in order to compare the two preparation methods (objective evaluation).

Regarding the haptic simulator preparations, they were acquired using our universities three Simodont® Dental Trainers (MOOG, Nissin, Netherlands) after the students had completed the obligatory typodont preparations and presented the necessary images of tooth #15. User accounts with unique codes were created for each participant to distinguish each preparation at the end of the task. Students received a verbal explanation of the task and equipment use. For the purposes of this research protocol, a case was created using Simodont® Dental Trainer software. The following diamond burs were selected: a 1.6 mm cylindroconical burr, a 1.2 mm cylindroconical burr, a 1 mm cylindrical burr, a flame burr, and a football burr. Along with the diamond burrs, identical polishing burs were included in the setup as well.

The exercise created for this task ensured that all drills the students had used in the lab were available and that all students could complete the same task. The device was set up to work with force feedback. Students were allowed to use the device and familiarize themselves with the artificial environment for 5 minutes. During this time, they were able to ask for explanations and assistance while performing a trial preparation. The students were allowed to zoom in and rotate the virtual tissue/organ. The system was then reset, and they had 30 minutes to perform the final crown preparation on the upper right second premolar (#15). Each participant's work was saved for further processing. At the end of the experiment, all haptic preparations were retrieved from the instructor's station; two images were taken of each haptic preparation, one from the buccal side (haptic mesiodistal TOC) and one from the mesial side (haptic buccolingual TOC).

In the end, each participant had four TOC measurement, two from the typodont preparation (typodont mesiodistal and typodont buccolingual TOC) and two from the haptic preparation (haptic mesiodistal and haptic buccolingual TOC). All measurements from the images were conducted using the Archicad Software by a built-in digital protractor in order to provide a repeatable and accurate procedure for the angle measurement. Tangents were drawn with the maximum number of contacts with the prepared walls to depict their general tendency of convergence. The resulting angle between the two tangents was then automatically measured using the software. The abovementioned process was repeated for every image of both typodont and simulator preparations. Measurements of the TOC angles were made by two individual investigators and the average mean of the two measurements was used. All values collected from this procedure were used for statistical analysis.

Questionnaire: A 23-item questionnaire was modified from Li *et al*.[5]; it was answered using a QR-generated code and was anonymous. The content of the questionnaire can be found in Table 1. The results were analyzed and visualized by pie charts or bar graphs.

Statistical analysis: Mesiodistal and buccolingual TOC values were compared between the two methods (typodont crown preparations and virtual crown preparations) using paired samples t-test at confident interval = 95%. All statistical analyses were performed using SPSS software.

RESULTS

RESULTS OF THE TOC MEASUREMENTS

An initial sample of 54 paired measurements of the TOC angle of a prepared tooth was used to compare possible differences using two different methods (Typodont Vs Haptic method).

A paired samples t-test was conducted to determine the effect of utilizing haptics to prepare a tooth on the mesiodistal TOC angle. Specifically, the resulting angle for each preparation method, Typodont Vs Haptics simulator, was measured. The resulting mesiodistal TOC angle using the Haptic simulator (M=9.45; SD=7.26) was significantly higher than using the traditional Typodont method (M=4.18; SD=2.91), t (53) = -4.989, $p < .001$. The 95% confidence interval of the difference between the means of the resulting angle ranged from [-7.40 to -3.16] and indicates a significant difference between the means of the samples.

Once again, a paired samples t-test was conducted to determine the effect of haptics on preparing a tooth in the buccolingual TOC, where the resulting angle for each preparation method, Typodont Vs Haptics simulator, was measured. The buccolingual TOC angle using the dental Haptics (M=11.23; SD=11.97) was significantly higher than the one resulting from the Typodont preparations (M=3.83; SD=3.51), t (53) = -4.526, $p < .001$. The 95% confidence interval of the difference between the means of the resulting angle ranged from [-10.69 to -4.12] and indicates a significant difference between the means of the samples. The generated angles for each preparation method (Typodont Vs Haptics method) in mesiodistal and buccolingual TOC are illustrated graphically via the use of box plots *(Figure 2)*.

RESULTS OF THE QUESTIONNAIRE

The sex ratio of the study sample was 1:1. Half of the participants (50%) had never played a VR game in the past, while 3% reported playing VR video games frequently. Only three participants had ever used a dental simulator (4.6%) *(Figure 3)*.

Seventy percent (70%) of the students indicated that they did not have much difficulty using a typodont, while approximately the same percentage indicated that had the same difficulty preparing a crown on a dental simulator. Achieving accurate

ejprd.org - Published by Dennis Barber Journals. Copyright ©2024 by Dennis Barber Ltd. All rights reserved.

Table 1. 23-item Questionnaire evaluating students' perceptions towards the utilization of haptics device and crown preparations.

Question	Provided Answer Selection
Gender	Male, Female, Open (Other)
Have you used a Dental Simulator before?	Yes, No
Have you played a Virtual Reality (VR) video game in the past?	Yes often, Few times, No never
Did you have difficulty working on a typodont?	Yes a lot, Not more than normal, Not at all
Did you face the same difficulties when preparing a crown on a Dental Simulator?	Yes, Open (No)
Dental Simulators can inspire you to learn	Disagree - Agree Scale (1-4)
I would like to use a Dental Simulator for skills training in the future	Strongly Agree, Partially Agree, Partially Disagree, Strongly Disagree
Dental Simulators are suitable for dental students in crown preparation skills training	Strongly Agree, Partially Agree, Partially Disagree, Strongly Disagree
Crown preparation training with the simulator will improve my preparation skills in real life	Strongly Agree, Partially Agree, Partially Disagree, Strongly Disagree
My overall experience of the Dental Simulator was pleasant	Strongly Agree, Partially Agree, Partially Disagree, Strongly Disagree
The Dental Simulators were easy to use	Strongly Agree, Partially Agree, Partially Disagree, Strongly Disagree
The Haptic tooth prearation process was accuratly simulated	Strongly Agree, Partially Agree, Partially Disagree, Strongly Disagree
The Odontoscope reflection was realistic	Strongly Agree, Partially Agree, Partially Disagree, Strongly Disagree
The force feedback of the tooth / typodont was realistic	Strongly Agree, Partially Agree, Partially Disagree, Strongly Disagree
The grip of the virtual instruments was comfortable	Strongly Agree, Partially Agree, Partially Disagree, Strongly Disagree
The appearance of the virtual oral instruments was realistic	Strongly Agree, Partially Agree, Partially Disagree, Strongly Disagree
The wearing comfort of the eyewear was satisfactory	Strongly Agree, Partially Agree, Partially Disagree, Strongly Disagree
The resolution of the screen was satisfactory	Strongly Agree, Partially Agree, Partially Disagree, Strongly Disagree
What was the most difficult part of preparing on a Dental Simulator?	Accurate reduction, Defining the margins, Making the preparation smooth, Open (Other)
How do you find preparing on a simulator compaired to a typodont?	Easier, Harder
Would you prefer working on a typodont or a Dental Simulator?	Typodont, Dental Simulator
Do you feel that practicing on a Dental Simulator could make the transition from a typodont to a phantom head easier?	Yes, No
Suggestions on how simulators could be utilized at EUC	Open

ejprd.org - Published by Dennis Barber Journals. Copyright ©2024 by Dennis Barber Ltd. All rights reserved.

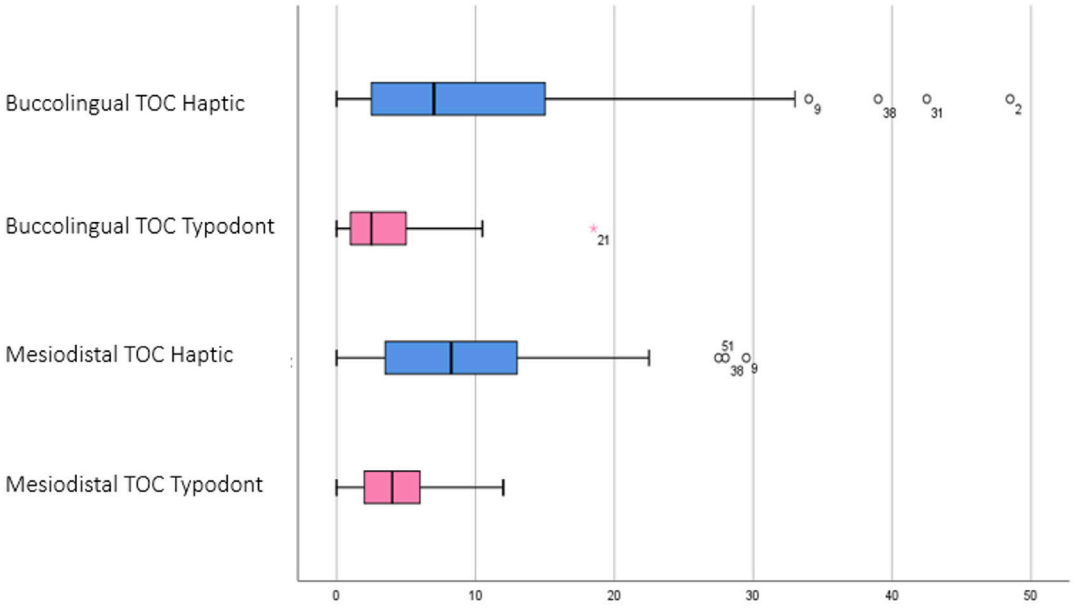

Figure 2: Box-plots of the resulting mesiodistal and buccolingual TOC angles for each preparation method (traditional Vs simulator method).

Figure 3: Questionnaire results regarding Gender, Simulation and VR video game prior experience displayed as pie charts.

reduction (50%) was the most challenging aspect of haptics preparation, followed by smooth preparation (27%) and defining margins (23.5). The vast majority of students (88.2%) found working on the haptics more difficult than working on typodonts and would overall prefer working on a typodont. Two-thirds of the students felt the overall haptics experience was good (41.2%) or very good (35%). Moreover, half of the participants agreed that practicing with the haptics would make the transition to a phantom head easier *(Figure 4)*.

Regarding the questions asking students to rate the performance of the haptic device, more than 90% agreed or strongly agreed that the eyewear was comfortable and the screen resolution was good. Also, 80% also agreed or strongly agreed that the reflection and appearance of the instruments were realistic. About 65-70% said the grip was comfortable and the force feedback was realistic. Nevertheless, only half of the participants (50%) agreed or strongly agreed that the haptic device accurately simulated the tooth preparation process on a typodont *(Figure 5)*.

One-third of the participants (35-37%) strongly agreed that the haptic is suitable for training crown preparation for dental students, and subsequently, they would like to use it for this purpose in the future. Only 15% strongly disagreed with the aforementioned statements. Almost 40% agreed that this training will improve their preparation skills and that haptics can inspire student learning *(Figure 6)*.

Students who responded to the open-ended question about how they think haptics can be utilized in our university premises, stated that they should be introduced to students earlier, perhaps even in their freshman year, so they can get accustomed to the tooth preparation procedure. Additionally, it was mentioned that the students would like to practice more frequently prior to going to the phantom scope lab or entering the clinic. Others claimed the feeling was not as realistic as typodonts, nevertheless, they could use the haptics "just for fun!"

ejprd.org - Published by Dennis Barber Journals. Copyright ©2024 by Dennis Barber Ltd. All rights reserved.

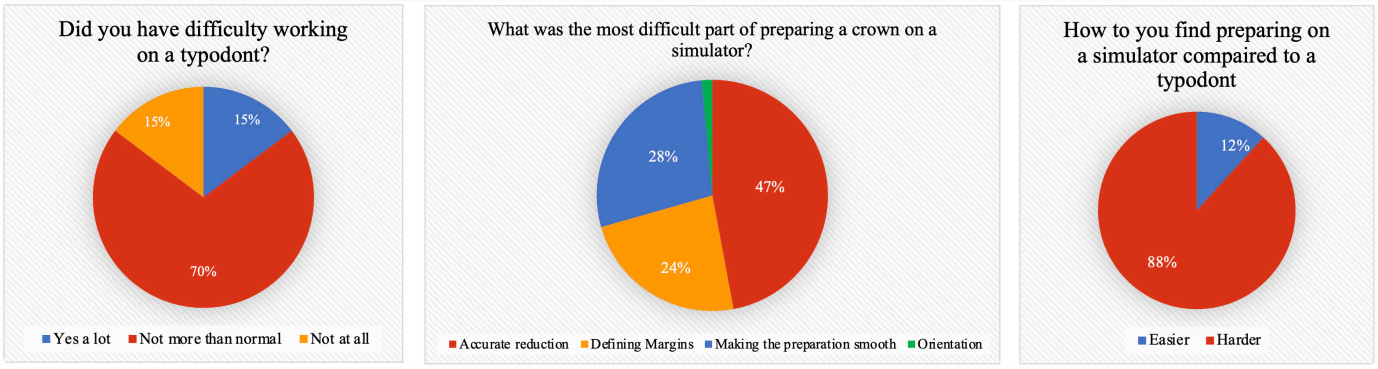

Figure 4: Questionnaire results regarding typodont difficulties, simulator difficulties and their comparison displayed as pie charts.

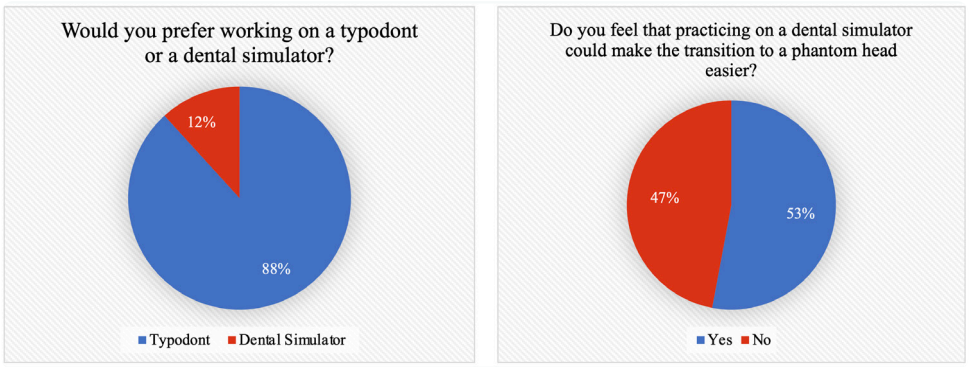

Figure 5: Questionnaire results regarding educational model preference, and weather the haptic dental simulator could provide an easier transition from typodont to phantom head simulators displayed as pie charts.

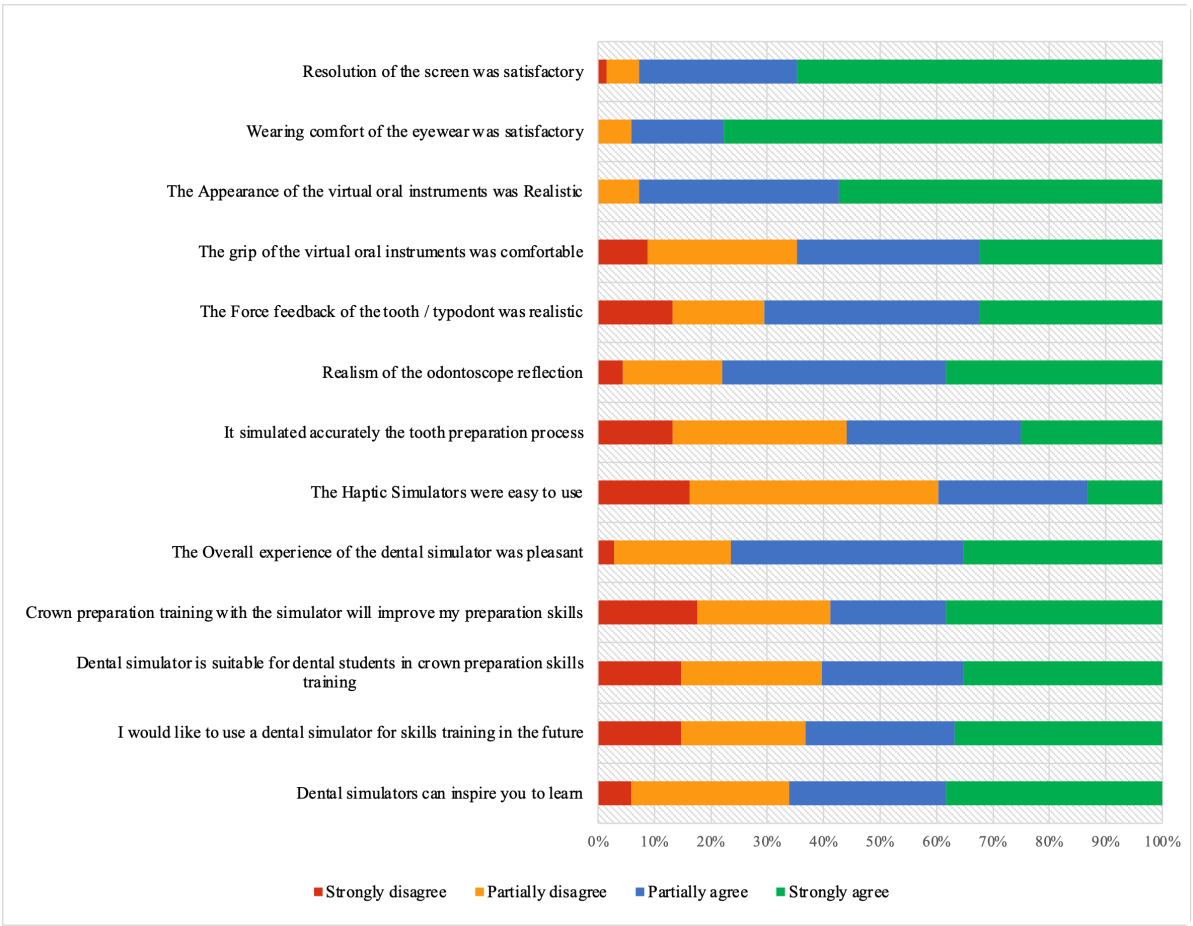

Figure 6: Questionnaire results regarding the haptic simulators ergonomics and overall experience expressed in a qualitative scale of; Strongly Disagree, Partially Disagree, Partially Agree, Strongly Agree.

ejprd.org - Published by Dennis Barber Journals. Copyright ©2024 by Dennis Barber Ltd. All rights reserved.

DISCUSSION

Objective evaluation of the second-year students' performance on the typodonts showed that they had a comparatively lower TOC angle when compared to other studies. In particular, Amine *et al*. found TOC angles of mesiodistal and buccolingual of 11.40° ± 5.09 and 12.58° ± 4.74 degrees, respectively, when using the typodont.[6–8] The quantitative results of our study showed that students preparations had lower TOC on the typodonts (Mesiodistal TOC = 4.18, Buccolingual TOC = 3.83) when compared to the haptic simulators (Mesiodistal TOC = 9.45, Buccolingual TOC = 11.23). There are several factors to take into consideration when viewing this difference. One important factor is that the students had 2 sessions of 1 hour and 40 minutes to prepare the premolar on a typodont. In the haptic experiment, they were only given one chance to prepare a tooth with a 5-minute familiarization period, and 30 minutes of preparation time. This fact, in addition with an expected learning curve associated with the haptic devices could mean that they could have performed even better if they had been given the same amount of time for virtual preparation. Other experimental setups offered more trials, but the lack of more haptic devices (only three available devices at our institution) and the large number of students (54 participants) discouraged offering another trial due to time constraints.[7,8]

Clinically, the difference in TOC values obtained from the typodont and the haptic simulator preparations would result in different tensile retention and thus could alter the success of the crown. In theory, the smaller the TOC angle the greater the retention of the crown along the preparation, but clinically, parallel walls with no undercuts are not always achievable or desirable. Hence, multiple TOC degree margins have been proposed as guidelines for clinicians and academics to strive for.[9,10]

In the past, it has been shown that students prepare lower TOC angles during preclinical training compared to clinical preparations.[11] Nevertheless, a student who performs well on the preclinical test VR is more likely to perform well clinically, as shown by Al-Saud, where the preclinical test VR proved to be a predictor of the student's clinical performance.[12] It has also been shown that the preparations performed on simulators can distinguish the level of expertise.[13] Our results regarding the TOC angles of the typodont preparations are closer to the 2-5 degrees suggested by Prothero.[14] Whereas the values obtained with the haptic device are in the range of 10-20 degrees suggested by Wilson and Chan,[15] showing that preparations between 6-12 degrees provide maximum tensile retention.

As for the responses to the satisfaction questionnaire, the items were modified from a paper by Li *et al*., as indicated in the corresponding section. Hence, our results are discussed in comparison with those.[16] Overall, many similarities and many differences were found. Similarities were observed in tasks related to the appearance of virtual objects and how students felt about using the device. Specifically, these similarities were obtained by isolating items that students agreed or strongly agreed with, such as the realism of the odontoscope reflection, the force feedback, the comfortable grip of the virtual instruments, the appearance of the virtual instruments, and the comfort of wearing the eyewear. Screen resolution was the only technical aspect where there was a difference of more than 60%. In our study, there were more than 90% positive responses, which was significantly higher than the 30% satisfaction level found in Li's study.[16]

Overall, the students presented a positive experience with the haptic devices (76.2%) and the majority suggested its use as an additional training method in preclinical stages. Those qualitative results come in accordance with qualitative evidence from other studies proving the haptic simulators to be a powerful educational tool.[17] Additionally, literature has shown the effect of haptic devices on the improvement of manual dexterity skill acquisition and their ability to predict clinical skill level, further reinforcing the rationale for their preclinical use.[18,19]

In comparison to Li's research, there was a difference of more than 20% in agreement or strong agreement for the remaining questions, with Li's percentages being higher than in our study.[5] These questions concerned students' perceptions of the ease of use of the device, the feeling that crown preparation training with the haptic would improve their preparation skills, whether the haptic is suitable for dental students to use for crown preparation skills training, if they would like to use haptics to train the skills in the future, and whether haptics can inspire students to learn. Although there were differences on the aforementioned points, participants in this study equally agreed that their overall experience with the haptic was positive (75%), which is consistent with the results of Li *et al*. (80%).[16] This indicated that our students were stricter with themselves despite the positive experience with the AR environment. This can be explained by the fact that they believed they performed worse with the haptics than with the typodonts and judged themselves according to very strict criteria.

CONCLUSION

Although students did not seem to prefer haptics over the typodont method, haptics appear to be a powerful tool in the student education process and deserve a permanent place in dental institutions as they can be a complementary option to traditional methods for education at the preclinical level.

LIMITATIONS

This current study poses certain limitations that need to be taken into account when conducting further research on this topic. One limitation posed is the technique used to measure the TOC angle of the preparations. Though the students were instructed in detail on how to frame their typodont preparation

ejprd.org - Published by Dennis Barber Journals. Copyright ©2024 by Dennis Barber Ltd. All rights reserved.

in the photographs, there could be a certain amount of variation in the angle, thus affecting our results. A possible improved technique would be for the typodont preparations to be scanned and their TOC be measured within a 3D interface software, such as prepCheck. This could not be implemented in our study since the 3D interface of the current MOOG Haptic Simulator software did not allow this type of measurement to be made, and subsequently would induce additional variability between the measurements of the typodont and the haptic machines. Were someone to use a Haptic Simulator software allowing for this direct 3D measurement, it would improve the accuracy of the values.

REFERENCES

1. Bakker, D., Lagerweij, M., Wesselink, P. and Vervoorn, M. Transfer of manual dexterity skills acquired in the Simodont, a dental haptictrainer with a virtual environment, to reality: a pilot study. *Bio-Algorithms and Med-Systems*. 2010; **6**:21–24.
2. Liu, L., Zhou, R., Yuan, S., Sun, Z., Lu, X., Li, J., *et al*. Simulation training for ceramic crown preparation in the dental setting using a virtual educational system. *Eur J Dent Educ* . 2020; **24**:199–206.
3. Imran, E., Adanir, N. and Khurshid, Z. Significance of haptic and virtual reality simulation (VRS) in the dental education: A review of literature. *Applied Sciences (Switzerland)*. 2021; **11**.
4. Bhandari, A., Jain, V. and Bhandari, R. Virtual and augmented reality: Changing horizons in dentistry. Vol. 6, *Defence Life Science Journal*. Defense Scientific Information and Documentation Centre; 2021. p. 323–329.
5. Li, Y., Ye, H., Wu, S., Zhao, X., Liu, Y., Lv, L., *et al*. Mixed Reality and Haptic-Based Dental Simulator for Tooth Preparation: Research, Development, and Preliminary Evaluation. *JMIR Serious Games*. 2022; **10**: e30653.
6. Amine, M., Wahid, H.O., Fahi, S., Lehmouddi, S., Hamza, M. and Elarabi, S. Assessment of Convergence Angle of Tooth Preparations for Complete Crowns Among Dental Students: Typodont vs Simulator. *Int J Dent*. 2022; **2022**:7615892.
7. Suebnukarn, S., Phatthanasathiankul, N., Sombatweroje, S., Rhienmora, P. and Haddawy, P. Process and outcome measures of expert/novice performance on a haptic virtual reality system. *J Dent*. 2009; **37**:658–665.
8. Kikuchi, H., Ikeda, M. and Araki, K. Evaluation of a Virtual Reality Simulation System for Porcelain Fused to Metal Crown Preparation at Tokyo Medical and Dental University. *J Dent Educ*. 2013; **77**:782–792.
9. Sadid-Zadeh, R., Sahraoui, H., Lawson, B. and Cox, R. Assessment of tooth preparations submitted to dental laboratories for fabrication of monolithic zirconia crowns. *Dent J (Basel)*. 2021; **9**:112.
10. Dhanraj, M., Ranganathan, H., Jain, A.R. and Varma, A.C.U. Effect of tooth surface modifications influencing retention in complete veneer restorations - A systematic review and meta analysis. *Biomedical and Pharmacology Journal*. 2017; **10**:927–936.
11. Goodacre CJ, Campagni W V, Aquilino SA. Tooth preparations for complete crowns: An art form based on scientific principles. *J Prosthet Dent*. 2001; **85**:363-376
12. Al-Saud, L.M., Mushtaq, F., Mann, R.P., Mirghani, I,. Balkhoyor, A., Harris, R., *et al*. Early assessment with a virtual reality haptic simulator predicts performance in clinical practice. *BMJ Simul Technol Enhanc Learn*. 2020; **6**:274–278.
13. Wang, F., Liu, Y., Tian, M., Zhang, Y., Zhang, S. and Chen, J. *Application of a 3D Haptic Virtual Reality Simulation System for Dental Crown Preparation Training*. 2016; 424-427. 10.1109/ITME.2016.0101.
14. James Harrison Prothero. *Prosthetic Dentistry. Third edition*. Chicago: Medico-Dental Publishing Company ; 1923. p742.
15. Wilson, A.H. and Chan, D.C.N. The Relationship Between Preparation Convergence and Retention of Extracoronal Retainers. *J Prosthodont* 1994; **3**:74-78.
16. Li, Y., Ye, H., Wu, S., Zhao, X., Liu, Y., Lv, L., *et al*. Mixed Reality and Haptic-Based Dental Simulator for Tooth Preparation: Research, Development, and Preliminary Evaluation. *JMIR Serious Games*. 2022; **10**: e30653
17. Eve, E.J., Koo, S., Alshihri, A.A., Cormier, J., Kozhenikov, M., Donoff, R.B., *et al*. Performance of Dental Students Versus Prosthodontics Residents on a 3D Immersive Haptic Simulator. *J Dent Educ*. 2014; **78**:630–637.
18. Gal, G. Ben, Weiss, E.I., Gafni, N. and Ziv, A. Preliminary Assessment of Faculty and Student Perception of a Haptic Virtual Reality Simulator for Training Dental Manual Dexterity. *J Dent Educ*. 2011; **75**:496–504.
19. Al-Saud, L.M. The utility of haptic simulation in early restorative dental training: A scoping review. *J Dent Educ*. 2021; **85**:704–721.

ejprd.org - Published by Dennis Barber Journals. Copyright ©2024 by Dennis Barber Ltd. All rights reserved.