Students' and tutors' perceptions of a deliberate simulated practice using patient-specific virtual and 3D-printed teeth models

Abstract

Objective: This pilot study aimed to investigate the perceptions of dental students and their tutors of a deliberate simulated practice using patient-specific virtual and 3D-printed teeth models before they performed their first indirect posterior tooth restoration on their patients.

Methods: Seventy-eight fourth-year dental students from the 2021 Comprehensive Clinic I course at the University of [redacted]ile, were invited to participate in a deliberate practice protocol. This consisted of digitally scanning their patients' teeth, printing the files three-dimensionally, and loading them into a virtual reality dental simulator to create patient-specific models. Subsequently, they practiced the same indirect posterior restorations on these models before performing them on their actual patients. Perceptions about students' preparedness to perform tooth preparations before and after the protocol were collected from students and their tutors.

Results: Sixty-three students (43 female) and six clinical tutors (all male) participated in the study. Before practicing with their patient-specific models, most students believed they had the knowledge, practical skills, and self-confidence to perform indirect restorations on their patients. However, after the protocol, most students thought their self-confidence increased and felt better prepared to treat their patients. Most students preferred the 3D-printed models over the virtual reality models to practice but mentioned that it did not feel like drilling dental enamel. Tutors believed that participating students had higher self-confidence when treating their patients and were more autonomous.

Conclusions: This study demonstrated that students and clinical tutors had positive perceptions of practicing with patient-specific virtual and 3D-printed teeth models before students performed their first indirect restorations on their patients.

Keywords: dental education, virtual reality, 3D printing, clinical training.

Introduction

Simulation is a didactic strategy that can be used to facilitate learning, whether in the cognitive, psychomotor, or affective domains and can include a wide range of activities and approaches for novices to experts.[1] Accordingly, simulation-based education allows experiential learning that enables students to practice various tasks without risk to patients,[2] to provide a smooth transition from pre-clinical to clinical environments.[3]

In dental education, lifelike mannequins (phantom heads) with articulating jaws, plastic teeth, and cheeks designed to reproduce the key aspects of dental patients and all the ergonomic aspects of clinical dentistry,[4] have become the standard of pre-clinical training.[3] This procedure is designed to improve students' fine motor skills and hand-eye coordination, along with self-assessment of their progress to facilitate the development of reflective practice,[5] and to transfer these skills to the clinic where actual patients are treated.[6]

Simulation allows students to practice and master a wide range of task-specific technical skills that are unique to dentistry,[7, 8] and it is *sine qua non* in dental education.[9] This is important because the nature of most operative procedures in dentistry are invasive and irreversible.[10] Accordingly, dental students' clinical simulation practice has always been an essential part of their training to develop the procedural and perceptual-motor skills,[11] to narrow the gap with the clinical phase of their education,[12, 13] adding experience before the provision of direct patient care.[14] It would be unusual to allow a dental student to perform a clinical activity without having previously practiced it in a simulated environment.[11]

Before the introduction of phantom heads, pioneers of dental education began to use extracted teeth for dental skills training,[14] though this is increasingly rare.[10] Nowadays, these mannequins incorporate synthetic resin teeth, gingiva and the palate, water spray, and dental handpieces, allowing students to practice their skills in relatively realistic environments for

diagnosis and treatment. However, the students are usually presented with standardized models, providing them with only a generic experience of real patient procedures.[15]

Although less widespread but becoming increasingly extensive, virtual reality (VR) dental clinical simulators with computer-generated teeth are achieving recognition as a valuable means to train dental students.[16] Further, haptic simulators that receive and transmit motion signals to mimic the interaction force between the bur and the different tooth structures (sensory feedback) are the latest improvements to simulation training, providing a safe learning environment.[8, 10, 14, 17, 18]

However, because of the diversity of teeth shapes, positions, and patient conditions found in the clinic, these training methods may not necessarily reflect the students' actual performance in real clinical cases.[19, 20] Thus, new developments in dental simulation training include the combination of patient-specific VR exercises and 3D-printed models.[10, 15, 19] The former involves drillable interactive 3D virtual models scanned from real patients displayed in VR dental simulators, while in the latter, a 3D model of the patient's teeth is printed for the students to practice, both with the intention of offering patient-centered and personalized training experiences.

All of the above pre-clinical training methods seek to narrow the "gap" between the transition from simulated cases to the treatment of real patients in which the students become responsible for patient care. However, it has been observed that this transition, at the beginning of students' clinical training, is a sensitive and stressful moment of their education,[12, 13, 21] which may affect their own competence confidence[22] and performance,[21] especially when confronted with patients' clinical uniqueness or anatomical diversity in irreversible treatments.[19]

To date, little research has explored the impact on students' perceptions of simulated practice using both 3D-printed and VR patient-specific models that reflect each patient's unique dentition. Thus, this pilot study, based on deliberate practice theory,[23] aimed to investigate the perceptions of dental students and their tutors about a deliberate simulated practice using

patient-specific virtual and 3D-printed teeth models before they performed their first indirect posterior tooth restoration on their patients, in order to help bridge the gap between simulation and the clinic, allowing them to practice the same procedure in advance that they will have to perform on their patients. These students had little clinical experience as they had only worked assisting fifth-year peers during their third year of study, and therefore were starting to treat patients on their own.

Materials and methods

Ethical approval

The Faculty of Medicine Scientific Ethical Committee of the University of [redacted] reviewed and approved the study (reference number: CEC202021).

Perceptions' questionnaires

Based on previous studies[10, 19, 24] and our own experience, three short draft questionnaires were developed. The first one contained three Likert-style items and assessed dental students' perceptions about their preparedness to perform a tooth crown and/or an onlay before performing it on their patients. The second one, which comprised eight items (seven Likert-style items and one open-ended question for comments), evaluated their perceptions about the experience of having practiced their crown and/or onlay preparations of their patients on the 3D-printed teeth and virtual reality (Simodont®) models after treating their patients. The third one evaluated the perceptions of clinical tutors about their students' self-confidence in treating their patients, autonomy to restore the tooth, and overall quality of the treatment. During successive feedback from several drafts of the questionnaires, three final-year students and four clinical instructors were asked to validate the forms.

Study protocol

When the participating students had been approved a treatment plan to perform a crown and/or an onlay, they took impressions with alginate and poured them with plaster to produce

diagnostic models for their patients. One researcher scanned the models with a CEREC Omnicam (Dentsply Sirona, York, Pennsylvania, USA), and exported them in stereolithography (STL) format to be designed as a solid block using a 3D design software (Meshmixer, Autodesk, San Rafael, California, USA). Subsequently, the STL files were three-dimensionally printed in the same dimensions as a single material using a 3D printer with a photopolymer temporary crown and bridge rigid resin material color Vita A2 (Form3 - Formlabs, Somerville, Massachusetts, USA). Furthermore, the same STL files of the patients' teeth were imported into a virtual reality dental simulator (Simodont® dental trainer, Nissin Dental Products Europe BV, Nieuw-Vennep, Netherlands) to create a patient-specific virtual model.

Participants and data collection

After successfully completing pre-clinical operative skills training in the third year of 2020, all 78 fourth-year dental students of the 2021 Comprehensive Clinic I course were invited to voluntarily participate in the study (68% female, mean age 22.5 y, SD 0.8). At the same time, and once the clinical case was approved by the tutors and before performing any treatment on their consented patients, students were asked to sign a written consent and anonymously completed the first pen-and-paper questionnaire to assess their perceptions of their preparedness to perform a posterior indirect restoration. During the successive days before starting their crown and/or onlay in the clinic, students attended the simulation lab to practice the indirect posterior preparations on their patients' 3D-printed models mounted on phantom heads using disposable mounting plates (Great Lakes, Tonawanda, New York, USA), and on the patient-specific virtual models loaded into the Simodont® simulators. Each student received two 3D-printed models to practice, in addition to being able to do so as many times as they wanted in the virtual simulators; instruments were the same as those used in the clinic. During all practicing sessions in the simulation lab, three instructors were available to provide students with systematic and immediate feedback to stimulate self-reflection. Students kept their models with the crown and/or onlay preparations in order to show them to their clinical tutors before

they performed the actual treatment on their patients to receive feedback on how to improve the tooth preparation.

Subsequently, after they completed the clinical supervised approved restorations on their patients, they were asked to anonymously complete the second pen-and-paper questionnaire to evaluate their perceptions about the experience of having practiced their crown and/or onlay preparations of their patients on the 3D-printed teeth and virtual reality (Simodont®) models. Further, clinical tutors of the same students were asked to complete the third questionnaire about their students' performances during tooth preparation.

Data analysis

Likert-style answers from the three questionnaires were first descriptively studied. Subsequently, the first and second questionnaire items were analyzed using a chi-squared test to determine whether there was a statistically significant difference ($p < 0.05$) between students' opinions. The data were organized into Microsoft Excel spreadsheets (Microsoft Excel, Microsoft Inc., Washington, USA) and statistically processed using SPSS Windows® version 27 (SPSS IBM Inc., USA).

The same researcher (JT) studied all qualitative comments from the students' second questionnaire after finalizing the treatment on their patients by identifying, analyzing, and reporting patterns to form themes and dimensions.

Results

A total of sixty-three students (81% of the class; 43 females and 20 males) and six male clinical tutors (all of the course trainers) participated in the study and completed the requested questionnaires.

Prior to conducting any analysis, a statistical test was performed to determine whether there were any significant differences by sex. As the result showed no difference in any category ($p \geq 0.392$), the sample was analyzed as one.

The responses to the first questionnaire asking dental students' perceptions about their preparedness to perform a crown and/or an onlay before preparing the tooth for the first time on their patients are shown in Figure 1.

Similarly, Table 1 shows the results of the same students' perceptions about the deliberate practice experience of practicing their crown and/or onlay preparations of their patients on the 3D-printed teeth and virtual reality models after treating their patients (second questionnaire).

A total of 73% of the participants preferred the 3D-printed models to practice their hands-on skills, 25% preferred Simodont®, and 2% did not like either simulation. However, 95% suggested that practicing both modalities together was the best option.

Students' qualitative comments about their experiences of having practiced their tooth preparations of their patients on the 3D-printed teeth and virtual reality models were identified and organized in themes and dimensions (Table 2).

Concerning clinical tutors' perceptions of their students' experiences after practicing with 3D-printed teeth and virtual reality models, 83% (17% neutral) believed that the students had higher self-confidence when treating their patients; 50% (50% neutral) thought they performed their tooth preparation more autonomously, and 83% (17% neutral) considered the students had obtained a better overall quality of their performed treatments.

Discussion

This pilot study aimed to explore the perceptions of dental students and their tutors of a deliberate simulated practice using patient-specific virtual and 3D-printed teeth models before they performed their first indirect posterior restorations on their patients. Our purpose was to help bridge the gap between simulation and clinical practice. An interesting aspect is that while the study participation was entirely voluntary, a large number of students decided to take part

in it: 81% of the class. This might be because the students felt that the experience offered them a risk-free environment to practice the actual treatment of their patients.[10]

Prior to practicing with their patient-specific models, most students believed they had the knowledge (68%), practical skills (68%), and self-confidence (52%) to perform the indirect restoration on their patients (Figure 1). Accordingly, there were fewer students who felt unprepared regarding their knowledge (8%) when compared to their practical skills (16%) and self-confidence (21%).

Regarding the patient-specific 3D-printed teeth and VR experience, 91% of the participating students thought it was interesting; this is very similar to the 89% of students who thought the same in the study by Lee et al.[19] when practicing with 3D-printed teeth. Further, 78% of our students disagreed with the statement that their experience was not helpful in developing their practical skills (Table 1). Similarly, 65% of participants expressed their desire for additional practice before performing the actual treatment, despite having expressed that they felt they had the knowledge and practical skills to treat their patients (Figure 1). This can be interpreted to mean that they felt prepared, but still thought they could develop their skills further. A similar study with 3D-printed teeth (not VR models) conducted on 45 third-year dental students in Korea found that more than 80% of participants gave positive feedback after practicing for a single crown abutment with 3D-printed customized typodont models before conducting the actual treatment on their patients.[19]

Students' perception of their self-confidence in performing a posterior indirect tooth restoration increased from 52% before the deliberate practice experience to 82% after performing their tooth preparation in the 3D and VR models; this difference was statistically significant ($p \geq 0.0001$). Self-confidence was also an emerging theme (Table 2), as it was a recurrent comment in the open-ended question answered by students after practicing in both model formats. Furthermore, 83% of clinical tutors believed that those students who participated in the study had higher self-confidence compared to those who did not participate.

This might be explained by the fact that self-confidence is related to the number of times a procedure is performed,[25] and that a frequent comment from students and teachers is that simulation is one factor that enhances students' confidence.[11] Further, it has been reported that dental students seemed less confident when performing the least-practiced procedures, such as indirect restorations[26] as in the current study.

The increase in self-confidence might be related to the feeling of being better prepared to treat their patients after practicing at their own pace with 3D and VR models that was expressed by 80% of the participants. This might also be related to a reduction in the cognitive load when students had to perform the treatment on their patients,[15] as clinical choices can be decided and practiced before the actual treatment. Another factor that might have contributed to the students' increased self-confidence after the deliberate practice exercise are the comments related to receiving timely and tailored feedback from tutors during the 3D-printed and VR tooth preparations and again before performing the actual treatment on their patients (Table 2); this feedback was also valued by participants in the study by Towers et al.[15] As stated by Nassar & Tekian[27] in their critical review, to achieve the maximum benefits from simulation exercises, emphasis should be placed on opportune feedback and deliberate practice approaches.

The experience of practicing in 3D-printed and virtual models of their own patients was worth the time invested for most participants (Table 1), and exercising with the actual patient's model gave them the idea of how their tooth preparations had to be performed and what they looked like (Table 2). It is important to mention that twenty-two students attended the simulation lab to practice with both 3D-printed and virtual models more than once; some even asked to have more than the two agreed 3D-printed models per student to practice, despite the fact that 50% of students expressed, as a drawback, that the feeling of drilling was different from doing it over tooth enamel.

As previously reported,[15] most students (73%) in our study preferred the 3D-printed models over the VR simulation (25%) to practice their hands-on skills; 2% did not like either simulation. However, an important percentage of participants (95%) favored practicing both modalities together. Further, and as depicted in Table 2, and in agreement with previous studies,[15, 19, 24, 28] students highlighted that working with 3D-printed models was better than practicing with standard and generic model teeth.

Additionally, they acknowledged as something positive about VR models that could be amplified to observe tooth preparation details was that the treatment could be restarted as many times as desired to visualize how much "tissue" had been worn out as a way of interaction with the haptic device. This was true despite the fact that the system did not have a predefined ideal preparation for comparison. In a previous study, students also mentioned as something positive about VR models was that they allowed the students to zoom in, which aids in understanding tooth anatomy.[15] However, they also stated that they had difficulty working with both models (3D-printed and VR), on approximal surfaces as the structure was a single block with no interproximal space. In contrast, the study by Lee et al.[19] printed their customized typodonts separately rather than having them attached to the adjacent teeth, which meant that most participants (89%) stated that they could consider adjacent teeth when performing the proximal surface reduction.

Our students also mentioned that both 3D-printed (FormLabs temporary crown and bridge resin) and virtual models were softer than enamel; participants in the study by Towers et al.[15] found that 3D-printed teeth with FormLabs Grey Resin had an acceptable hardness. Our students highlighted that it was difficult to distinguish between hard and soft dental tissues, which was also reported previously,[19] as well as that decays and old fillings could not be differentiated. Further, they suggested that the VR simulator had an "undo" option to go back one step and that they could control the speed of the bur with the pedal.

Besides increasing students' self-confidence, the deliberate practice simulation exercise contributed positively to the students' autonomy in performing the tooth preparation as well as to the overall quality of the treatments they performed, as subjectively stated by their clinical tutors. This could be interpreted as the students increasing their clinical efficiency, providing better patient care. A similar opinion was also noted by participants themselves in a previous study.[15] However, one should be cautious when trying to relate efficiency with self-confidence, as in our study these were just perceptions.

Two important issues mentioned by students when using the VR simulation relate to having difficulty with the finger rest and getting accustomed to the drilling tactile sensitivity of the haptic device. It should be mentioned that, in contrast to the study by Towers et al.,[15] our fourth-year students only had limited practice with the virtual simulator when they were in their initial semesters of the course. This could have contributed to their preference for the 3D-printed models over the VR simulation, as they were familiar with them in working with the phantom heads.

Despite the positive perceptions of participating students, the current study had some limitations that students highlighted that might have influenced their opinions. The patient virtual models loaded into the VR simulator only had a limited mouth section restricted to three posterior teeth with a single hardness. Similarly, 3D-printed models could not differentiate tissue hardness, while as VR models, simulated tooth structure was a single block (no separation between teeth) that had the same rigidity and color as the simulated gingival tissue. Future studies with newly developed technologies might overcome these issues.

Conclusion

This study demonstrated the positive perceptions of students and clinical tutors about using patient-specific virtual and 3D-printed teeth models before the students performed their first tooth indirect restorations on their patients. Students valued the opportunity to practice their patients' posterior indirect restorations using 3D-printed and VR models before performing the

actual treatment and suggested that practicing with both modalities was the best option because they were complementary.

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The data pertaining to the findings of this study are available on request.

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Figure 1. Students' perceptions about their preparedness to perform a crown and/or an onlay before performing it for the first time on their patients (*p*-value of Chi-squared tests).

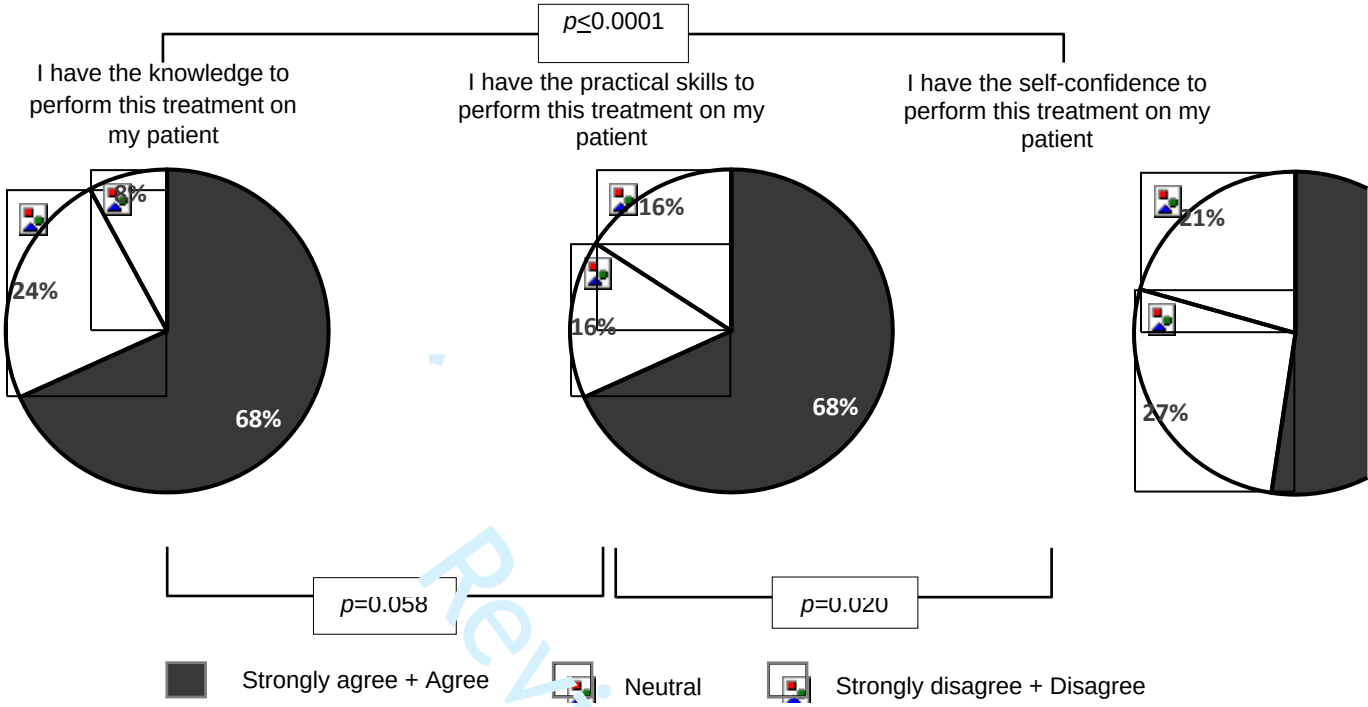

Table 1. Students' answers to the post-treatment questionnaire by the percentage of total respondents and the statistical significance for each statement: n=63. *p*-value of Chi-squared test.

Regarding the simulated practice both in 3D-printed models and Simodont®:				
Statement	Strongly agree + Agree	Neutral	Strongly disagree + Disagree	p-value
It was interesting	93%	4%	4%	≤0.0001
It was not helpful to develop my practical skills	9%	12%	79%	≤0.0001
It felt like drilling real dental enamel	27%	23%	50%	≤0.0001
I would like to be able to practice more times before treating my patients	68%	20%	12%	0.001
The time invested was not worth it	6%	15%	79%	≤0.0001
I have the self-confidence to perform this treatment on my patient	82%	12%	6%	≤0.0001
I feel more prepared to treat my patient after practicing with 3D and VR models	76%	18%	6%	≤0.0001

Table 2. Themes and dimensions identified in students' comments after they practiced with the 3D and virtual reality models after completing their patients' treatment.

Emerged themes	Data coding (dimensions)
Self-confidence	– Self-confidence increased after practicing with the 3D and VR models in a risk-free environment
	– Having practiced before with the reproduction of the real patient dentition was like working on familiar ground
	– Practicing before the treatment helped to know how to improve our skills
Practicing with 3D and VR models	– Having an advanced idea of how the tooth preparation has to be performed and what it should look like
	– Being able to check how much tooth structure had been worn out in VR
	– Practicing with the actual 3D-printed patient model is much better, useful, and authentic than doing it with standard and generic teeth models
	– Teeth model magnification and rotation in VR is useful to observe details
	– Restart the VR treatment as many times as you like
	– 3D and VR models are softer than tooth enamel
	– Teeth are in one block; it is difficult to work in approximal surfaces
	– The entire model is made of the same material; challenging to distinguish tooth from gingiva
	– Old restorations and caries that need to be removed cannot be differentiated
	– VR simulator could have an "undo" option to go back one step
	– VR simulator does not allow you to control the speed of the bur
	– Finger rests are difficult with the VR simulator
	– It takes a while to get used to the tactile sensitivity of the VR simulator when drilling
Feedback	– Receiving timely feedback from tutors about the prepared tooth in the 3D and VR models before performing the actual treatment in the patient was reassuring

Figure 2. Student practicing with patient-specific 3D-printed jaws mounted in a phantom head.

Figure 3. Patient-specific teeth model loaded into the virtual reality simulator for the students to practice their indirect posterior restorations.