First experiences with patient-centered training in virtual reality

Carlos M. Serrano1 | Paul R. Wesselink2 | Johanna M. Vervoorn3

1Evidence Based Clinic & Department of Educational Research and Development, Academic Centre for Dentistry Amsterdam (ACTA), Amsterdam, Netherlands
2Department of Cariology Endodontology & Pedodontology, Academic Centre for Dentistry Amsterdam (ACTA), Amsterdam, Netherlands
3Institute of Education, Academic Centre for Dentistry Amsterdam (ACTA), Amsterdam, Netherlands

Correspondence
Carlos M. Serrano, Academic Centre for Dentistry Amsterdam (ACTA), Gustav Mahlerlaan 3004–1081 LA, Amsterdam, Netherlands.
Email: c.serranopetrillo@acta.nl

Abstract

Context: In preclinical dental education, plastic and extracted teeth have been broadly used for skills training without specific focus on the patient behind the procedure. A patient-centered approach remains challenging in traditional simulation, which does not resemble realistic clinical situations.

Objective: This article describes the development and first experiences with a patient-centered virtual reality training module (PC-VR) that allows dental care providers to prepare, beforehand and in virtual reality (VR), specific procedures required by their patients. Experiences with this patient-centered practice are described to reflect on its value for clinical training in dentistry.

Design: Using an intraoral scanner, digital impressions of 10 patients were made; these served as stereolithography (STL) digital files, which were converted into volumetric haptic models for display in a VR dental simulator. In this study, students’ experiences were investigated through a short open-answer survey in 2018. Atlas.ti was used for qualitative analysis of the answers through the inductive methodology of the grounded theory approach.

Results: Drillable virtual models of real patients were made available for training using VR. Inductive analysis of the experiences identified 5 dimensions describing the main features of PC-VR: added value, competence development, self-efficacy, outcomes, and room for development.

Conclusion: This article provides a general overview of the possibilities and challenges of the implementation PC-VR in dental education. Although concrete effects on trainees’ self-confidence and performance are yet to be determined, all participants appreciated the opportunity to explore clinical situations before experiencing them in the context of a real patient.

KEYWORDS
computer simulation, patient simulation, patient-centered care, patient-centered training, virtual reality

1 | INTRODUCTION

Dental education is one of few disciplines where trainees must perform invasive treatments in real patients, under progressively decreasing levels of supervision, in order to achieve the clinical competence and confidence needed to independently provide safe care.1,2 This educational approach implies interesting educational, ethical, and safety questions: Is skills
training sufficient to enable comprehensive, patient-centered care. Are patients safe under the care of beginners? Are teachers and/or schools willing to assume this responsibility? Is it ethical to practice specific procedures for the first time on real patients?

Competence in general can be achieved through 3 interdependent stages: cognitive (learning about the procedure), associative (learning to perform the procedure), and autonomous (automating the steps of the procedure). In adult learning theory, competence development is completed through a consolidation phase, which includes a process of reflective practice or reflection on action that determines long-term stabilization of the skill/competence. In dental education, autonomous and consolidation phases are commonly developed by providing care to real patients. Although prior experience has demonstrated successful outcomes, this learning approach involves implicit risks for patients and an important degree of anxiety for students; its process is supervised by teachers who are often liable for problems associated with students’ performance, albeit within the general liability of the dental school.

Traditionally, mannequins with either plastic teeth or (increasingly rare) suitable extracted teeth have been used in initial phases of dental curricula for the associative and autonomous stages of competence development, mainly with a procedural approach. Several aspects to prepare for a patient-centered approach, including realistic cases and the opportunity to check clinical decisions or irreversible solutions, remain challenging in traditional simulation settings. These are primarily achieved by treating real patients in the clinic.

The American Dental Education Association Commission on Change and Innovation (ADEA CCI) 2.0, in its search for strategies to embrace the future changes in dental education and care, has set 3 goals to lead the path towards the future: (1) person-centered healthcare, (2) future-ready graduates, and (3) transformative learning environments.

With the focus on these ambitions for current and future dental education, contemporary technical developments in dentistry have allowed dental education to combine various technologies to design patient-centered, comprehensive, and personalized training experiences. These new training opportunities might facilitate the relocation of the autonomous and consolidation phases of skills development to a safer learning environment than patients.

Starting in the 1990s, several simulation methods based on new technologies have been introduced to provide a more comprehensive learning experience in dental education. Since, computer-aided trainers, augmented reality, and VR simulators have gained increasing relevance in dental education. Currently available dental VR training devices with sensory feedback (haptics) provide a safe learning environment to learn from basic motor skills to complex clinical procedures.

Several advantages of implementing VR simulation in dental education are related to the possibility to work with an extensive database of process-based recordings. This allows an analysis of students’ learning process that provides multiple feedback opportunities with a “knowledge of performance” approach instead of only assessing results. This database provides also a wide source for learning analytics and educational research.

From a dental perspective, the use of VR facilitates the development of students’ hand-eye coordination and fine-motor-skill learning during the preclinical phases. Skills developed in VR are transferable to reality, and VR can aid the retention of these skills. Moreover, VR simulation can discriminate among users with different skill levels, indicating a convergent validity that may facilitate measurement of dental performance and training. Virtual training modules are highly customizable to the learner’s level and needs, providing a low-stress and low-risk learning environment that allows unlimited training repetition.

Further implementation of VR simulation in the clinical phase of dental curricula has yet to be explored. The integration of these technologies with clinical training seems to unfold opportunities for the issues of patient safety, training and testing ethics, and standardization of clinical training in dental education.

An example of VR-haptic technology is the Simodont Dental Trainer (Nissin Dental Products Inc., Nieuw-Vennep, The Netherlands) (Figure 1), which offers the trainee a learning experience in a virtual environment with courseware, offering procedures ranging from manual dexterity exercises to virtual patients, thereby presenting clinical scenarios of different complexity. Stereoscopic (3D) vision of high-resolution dental models are provided as well as realistic sounds. The simulator consists of a robotic arm with a dental air rotor as active component, which provides haptic force feedback to the user with a feeling closely resembling all dental tissues, including the pulp chamber, as well as the different cutting behaviors of the various burs. Notably, this VR-haptic dental trainer enables interaction with intraoral digital impression devices.

This article describes the development and first experiences with a patient-centered virtual reality training module (PC-VR) that allows dental care providers to prepare patient-specific procedures before performing them in the clinic. Experiences with this patient-centered practice are described and analyzed to reflect on its value to clinical training in dentistry.

2 METHODS

The Institutional Review Board determined that this study was exempt from oversight (Ref. 201958). The default approach for production of haptic virtual models in dentistry begins
with a computed tomography (CT) scan of an anatomical structure. The 3D data obtained by the CT scan comprise volume elements or polygons known as voxels, where a voxel represents a value on a regular grid in 3D space. Using the marching cubes algorithm, superficial data describing the tooth can be interpreted. These data comprise a large number of equally sized polygons that can also be converted into density and color, based on voxel mapping.

To simulate a real patient in VR, digital impressions of the intraoral situation were performed to obtain a 3D rendering of the teeth, using an intraoral optical impression system (3M True Definition Scanner; 3M, St. Paul, MN, USA). The outcome was a high-resolution superficial digital representation with a triangulated mesh, in the stereolithography digital file (STL) format (Figure 2). A conversion software (Nissin Dental Products Inc.) was developed in cooperation with the Academic Centre for Dentistry Amsterdam (ACTA) and the Leeds Dental Institute; this software was used to “fill in” superficial STL files, such that they were converted to solid volumetric haptic models compatible with Simodont. Before creation of the volumetric model, a “clean-up” of the STL model was performed to ensure that all important segments of the scan were “watertight,” that is, no gaps were present that obstructed determination of the model limits; this step was performed using a specific software to manipulate triangle meshes (Autodesk Meshmixer, Autodesk Inc., San Rafael, CA, USA). When a scan was “watertight,” the area of interest in the model was defined with the Intraoral Cropper software (Nissin Dental Products Inc.). Subsequently, a volumetric haptic model, based on the original intraoral scan, was created by loading the output of the Intraoral Cropper into the Intraoral Software; this comprised a grid with a resolution of 0.2 mm containing the entire mesh. Each intersection in this grid constituted a voxel; the software reviewed all lines in the grid, checking for intersections. When an intersection was found, the position was registered to build the model.

Finally, the patients’ models were placed on the students’ personalized virtual “waiting room” on the Simodont. Every
FIGURE 3  Patient-centered virtual reality (PC-VR) training module: User’s interface

volumetric model could be explored with simulated hand instruments (i.e. dental probes, preparation meters) and cut with different sorts of burs. PC-VR users’ interface is shown in Figure 3.

Using this technology, 10 patients with an indication for a complex dental preparation to receive a posterior indirect restoration were included. These patients were treated by fourth and fifth year dentistry students, and were referred by the clinical teacher in charge because of their particular cavity-design complexity (inlay/onlays). Patients with indications for direct restorations were excluded. Digital impressions were made with patients’ informed consent and in accordance with the institutional patient data and information safety protocol. Real patients’ intraoral haptic volumetric models were placed in the Simodont Dental Trainer to allow practice in the VR environment, before performing irreversible interventions in these patients; this served as the PC-VR module. The complete PC-VR workflow and stages are shown in Figure 4.

Students experiences were investigated through a short open-answer survey that aimed to gain insight into the clinical situation, the motivation to participate in this pilot project, and the perceived learning value of the PC-VR. Participants’ answers were analyzed using the inductive methodology, through independent parallel coding. Two educational researchers of the school’s educational institute, carried out independent analysis extracting relevant concepts (codes) and forming thematic categories from the answers.23 The concepts identified within these data allowed the identification of general domains describing participants’ experience. Thematic relevance was identified through code prevalence in each category (“q”) and was registered as representation of their incidences in the data. Atlas.ti 8 (GmbH. Berlin, Germany) was used for the coding process.

3 | RESULTS

Ten fourth- and fifth-year dentistry students participated in this pilot program. Saturation was achieved after analysis of 7 student answers, but all replies were analyzed for confirmation. Inductive analysis of these answers resulted in 5 general categories that captured the main features of PC-VR: competence development (q = 40), value (q = 31), outcomes (q = 17), self-efficacy (q = 10), and room for development (q = 4). A summary of the qualitative results is shown in Table 1.

3.1 | Category 1: competence development with PC-VR

Within this category, competence-related constructs were grouped in accordance with different quote frequencies, such as identification of learning/training needs (q = 9), decision making/treatment planning (q = 9), training (q = 19), and efficiency (q = 3). Diverse learning/training needs were identified for this training, according to the nature of the
FIGURE 4  (a) Digital impression with intraoral scanner; (b) Intraoral situation; (c) Intraoral Cropper software; (d) Patient’s virtual model; (e) Procedure in VR; (f) Clinical result.

TABLE 1  Patient-centered virtual reality training module (PC-VR) first experiences qualitative analysis results overview

| Survey | Categories | Thematic relevance (q) | Example |
|--------|------------|------------------------|---------|
| What was your case about? | Indirect ceramic restoration | 10 | “I was appointed to treat a patient with a failed large composite filling on an endodontically treated 26… The decision was to treat with a lithium disilicate onlay.” |
| Why did you (and/or your teacher) decide to practice the treatment in Simodont first? | Complexity | 10 | “I had no clinical experience with partial crowns and I wanted to practice the treatment before I performed it on my patient” |
| How did this module help you? | Competence development | 40 | “I was able to practice precisely what I needed for this treatment.” |
|  | Value | 31 | “…you can make mistakes and see where the difficulties are.” |
|  | Outcomes | 17 | “After 3 attempts in VR, I was easily able to perform a suitable treatment.” |
|  | Self-efficacy | 10 | “I could practice in a less stressful environment which improved my performance during the actual treatment.” |
|  | Room for development | 4 | “…the movements in the patient are not the same and to work in the mouth is also different because of the tongue and saliva.” |
clinical situation and the level of expertise of the trainee (“I had no experience with this procedure”; “I was able to practice precisely what I needed for this treatment”). Participants also described that they were able to “determine the best course for the treatment” and “determine the approach to the procedure.” Regarding the training itself, participants mentioned the utility of gaining familiarity in advance with a specific clinical situation (“if you have practiced and know the situation, it can only go better”), the usefulness of repeated practice until the desired procedural and confidence levels were achieved (“it helped my confidence because I had practiced several times over”), and the importance of a proof of concept of the procedure for use in discussions with their teacher (“in that way there would be some proof of concept of the preparation prior to the exam”). Finally, participants stated that they “became faster” throughout the PC-VR and were thus able to easily perform the procedures in 1 session.

3.2 | Category 2: PC-VR value

Several quotes in this category addressed the technical advantages of the PC-VR ($q = 8$). These included the ability to achieve a better view of the clinical situation in the virtual environment (“The treatment became a lot more visual”) because of the rotating, lighting, and zooming capabilities of the dental trainer. The unlimited training opportunities (“I made the preparation several times again”), and the availability of an environment where “mistakes” are allowed and encouraged (i.e., for learning purposes), were also frequently mentioned as added benefits of PC-VR (“you can make mistakes and see where the difficulties are”). The most frequent quotes regarding value were related to clinical safety ($q = 11$).

3.3 | Category 3: outcomes

Quotes regarding user satisfaction and procedural outcomes were gathered in this category. Participants reported their satisfaction ($q = 8$) with PC-VR stating: “it helped me a lot,” “for me it was perfect to do it,” and “it was a very helpful training.” Statements related to procedural outcomes ($q = 9$) suggested that PC-VR aided in achieving satisfactory final performance of the specific treatment (“at the end the treatment on the patient was successful” and “after 3 attempts in VR, I was easily able to perform a suitable treatment”).

3.4 | Category 4: procedural self-efficacy with PC-VR

The concept of confidence was frequently mentioned ($q = 7$). Based on repetition and the ability to identify (in advance) possible challenges of the procedure, participants stated that the PC-VR allowed them to feel more confident regarding performance of the clinical treatment (“The training gave me the confidence to execute the task even when it was my first time”). Furthermore, according to the participants, the effect of stress on performance decreased upon use of the PC-VR ($q = 3$), as the procedure could be practiced in isolation from some clinical stress factors (“I could practice in a less stressful environment which improved my performance during the actual treatment”).

3.5 | Category 5: room for development

According to the participants, this technique in its current state presents certain limitations ($q = 4$), including the additional time that PC-VR adds to regular clinical training, as well as the differences between VR and the real clinical situation, for example, the absence of a different hardness for enamel and dentin, soft tissues, saliva, and patient movement (“the movements in the patient are not the same and to work in the mouth is also different because of the tongue and saliva”).

4 | DISCUSSION

PC-VR offers the opportunity to experience a real patient-specific clinical situation before applying the procedure to the real patient. According to the participants, this module enabled a better preparation for irreversible procedures, management of unexpected procedural complications, and prevention of possible damage. Based on these experiences it can be assumed that through PC-VR the trainee might be able to check their procedural decision-making processes and clinical skills, possibly improving the competence level later required for the specific clinical procedure. This may support the development of more competent and confident clinicians, especially when the training is placed in a learning environment without general clinical stress factors (e.g., pain or limited time), allowing the trainee to fully focus on the procedural learning needs.

From an experiential perspective and independently of professional experience, every new patient is a unique venture. Every new treatment planning and procedure is therefore a small experiment in itself with implicit risks. By placing the experimental phase of training for a procedure in a safer environment such as PC-VR, where the risks can be identified, controlled, and trained beforehand, it can be assumed that the safety of dental care might be increased.

Furthermore, PC-VR offers a range of training alternatives applicable for use in dental schools where there are often limited availability of suitable patients, as well as challenges in providing a standardized training experience to
Simulated cases can be used as training content in the official training curriculum enabling the possibility to provide all students with standardized minimum clinical experiences required according to their competence level, as a complement to traditional clinical training. The creation of a virtual library of real patients, after gathering several PC-VR cases, may offer the opportunity for predoctoral and postgraduate trainees to broaden their clinical exposure and make it less dependent on patient supply.

The capability of recording trainees progress, which provides evidence of both the learning process and readiness to perform, adds a further level of transparency and evidence for practitioners, teachers, and schools, also providing an interesting opportunity for interprofessional discussion and calibration. Ethical and safety issues in dental training, competence assessment, and patient care might also be addressed by using this technology. Importation and exportation opportunities of this technology may allow further preclinical/clinical integration, because training and performing a procedure can travel between reality and simulation by means of intraoral scanners and VR simulators, thus facilitating further interaction with other digital dental software programs and 3D printing/milling devices.

According to the participants, improvements in virtual models and further developments are needed to completely achieve the aim of a reality-based, fully haptic simulated training. The current capacity of the simulation device is restricted to virtual models only of a limited mouth section with a single hardness. Although improvements in the haptic feedback and range of the Simodont Dental Trainer are permanently introduced by the company, these are yet to be systematically tested. The current hardness of the PC-VR models is equivalent to the system’s virtual enamel. Internal anatomy, as well as differentiated haptic feedback for enamel, dentin, and caries, are desirable for a higher level of realism in the future.

Notably, the introduction of real patients in VR for dental training may allow the migration of the autonomous and consolidation phases of competence development from the dental chair to a simulated environment, ensuring that patient care is delivered by clinicians with verified skills. However, an important aspect of patient digitization processes is the compulsory confidentiality and safety of patient data, for which global and local regulations should be taken into consideration to properly manage developments in this technology.

5 | CONCLUSION

First experiences with PC-VR offer a general overview of the possibilities and challenges of the implementation of this new training module in dental education. Although concrete effects on the trainees’ self-confidence and performance are yet to be determined, all participants appreciated the opportunity to explore clinical situations before experiencing them in the context of a real patient.

ACKNOWLEDGMENTS

The authors sincerely thank the support of ACTA’s ICT&O department for their constant support, particularly Mr Pepijn Koopman and Mr Klaas-Jan van Egmond for their collaboration with this article. Likewise, Mr Niels van der Braber and Mrs Esther Buur for their crucial technical input to this development.

Finally, the authors would like to thank ACTA’s teachers and students for their willingness to collaborate, specially Mr Dan Milstein for sharing the documentation of his procedure.

DISCLOSURE

The authors declare no conflicts of interest. No funding was provided for this study.

The original development of the Simodont Dental Trainer was partly funded by ACTA and subsidized by the Ministry of Economic Affairs of The Netherlands (The Hague, The Netherlands). The Academic Centre for Dentistry Amsterdam receives royalties per unit sold as a return on investment in the development; the royalties are fully invested in continuous academic development of expanding the applications of the dental trainer.

REFERENCES

1. Perry S, Bridges SM, Burrow MF. A review of the use of simulation in dental education. *Simul Healthc*. 2015;10:31-37.
2. Chuenjitwongsa S, Oliver RG, Bullock AD. Competence, competency-based education, and undergraduate dental education: a discussion paper. *Eur J Dent Educ*. 2018;22:1-8.
3. Walji MF, Karimbux NY, Spielman AI. Person-centered care: opportunities and challenges for academic dental institutions and programs. *J Dent Educ*. 2017;81(11):1265-1272.
4. Kneebone RL, Scott W, Darzi A, Horrocks M. Simulation and clinical practice: strengthening the relationship. *Med Educ*. 2004;38:1095-1102.
5. Chu T-MG, Makhoul NM, Rodrigues Silva D, Gonzales TS, Letra A, Mays KA. Should live patient licensing examinations in dentistry be discontinued? Two viewpoints. *J Dent Educ*. 2018;82(3):246-251.
6. Formicola AJ, Shub JL, Murphy FJ. Banning live patients as test subjects on licensing examinations. *J Dent Educ*. 2002;66(5):605-609.
7. Taylor DCM, Hamdy H. Adult learning theories: implications for learning and teaching in medical education: aMEE Guide No. 83. *Med Teach*. 2013;35(11):e1561-e1572.
8. Serrano CM, Botelho MG, Wesselink PR, Vervoorn JM. Challenges in the transition to clinical training in dentistry: an ADEE special interest group initial report. *Eur J Dent Educ*. 2018;22(3):e451-e457.
9. Gottlieb R, Vervoorn JM, Buchanan J. Simulation in dentistry and oral health. In: Levine AI, De Maria S, Schwartz AD, eds. *The Comprehensive Textbook of Healthcare Simulation, Simulation in*
10. Palatta AM, Kassebaum DK, Gadbury-Amyot CC, et al. Change is here: aDEA CCI 2.0—a learning community for the advancement of dental education. *J Dent Educ.* 2017;81(6):640-648.

11. Brownstein SA, Murad A, Hunt RJ. Implementation of new technologies in U.S. dental school curricula. *J Dent Educ.* 2015;79(3):259-264.

12. Al-Saud LM, Mushtaq F, Allsop MJ, et al. Feedback and motor skill acquisition using a haptic dental simulator. *Eur J Dent Educ.* 2017;21(4):240-247.

13. De Boer IR, Bakker DR, Serrano CM, et al. Innovation in dental education: the “on-the-fly” approach to simultaneous development, implementation and evidence collection. *Eur J Dent Educ.* 2018;22(4):215-222.

14. Mirghani I, Mushtaq F, Allsop MJ, et al. Capturing differences in dental training using a virtual reality simulator. *Eur J Dent Educ.* 2018;22(1):67-71.

15. Eve EJ, Koo S, Alshihri AA, Cormier J, et al. Performance of dental students versus prosthodontics residents on a 3D immersive haptic simulator. *J Dent Educ.* 2014;78(4):630-637.

16. De Boer IR, Wesselink PR, Vervoorn JM. The creation of virtual teeth with and without tooth pathology for a virtual learning environment in dental education. *Eur J Dent Educ.* 2013;17(4):191-197.

17. De Boer IR, Lagerweij MD, Wesselink PR, Vervoorn JM. Evaluation of the appreciation of virtual teeth with and without pathology. *Eur J Dent Educ.* 2015;19(2):87-94.

18. De Boer IR, Wesselink PR, Vervoorn JM. Student performance and appreciation using 3D vs. 2D vision in a virtual learning environment. *Eur J Dent Educ.* 2016;20(3):142-147.

19. De Boer IR, Lagerweij MD, De Vries MW, Wesselink PR, Vervoorn JM. The effect of force feedback in a virtual learning environment on the performance and satisfaction of dental students. *Simul Healthc.* 2017;12(2):83-90.

20. Jockstad A. Computer-assisted technologies used in oral rehabilitation and the clinical documentation of alleged advantages—a systematic review. *J Oral Rehabil.* 2017;44(4):261-290.

21. Ting-Shu S, Jian S. Intraoral digital impression technique: a review. *J Prosthodont.* 2015;24(4):313-321.

22. Lorensen WE, Cline HE. Marching cubes: a high resolution 3D surface construction algorithm. *Comput Graph (ACM).* 1987;21(4):163-169.

23. Thomas DR. A general inductive approach for analyzing qualitative evaluation data. *Am J Eval.* 2006;27(2):237-246.

**How to cite this article:** Serrano CM, Wesselink PR, Vervoorn JM. First experiences with patient-centered training in virtual reality. *J Dent Educ.* 2020;84:607–614. https://doi.org/10.1002/jdd.12037