VR as innovation in dental education

Validation of a virtual reality environment: collecting evidence ‘on-the-fly’ during development and implementation

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Creation of virtual teeth with and without tooth pathology for a virtual learning environment in dental education

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ABSTRACT

**Purpose**
To describe the development and opportunities for implementation of virtual teeth with and without pathology for use in a virtual learning environment in dental education.

**Material and methods**
The creation of virtual teeth begins by scanning a tooth with a cone beam CT. The resulting scan consists of multiple two-dimensional greyscale images. The specially designed software program ColorMapEditor connects these two-dimensional images to create a three-dimensional tooth. With this software, any aspect of the tooth can be modified, including its colour, volume, shape and density, resulting in the creation of virtual teeth of any type.

**Results**
This article provides examples of realistic virtual teeth with and without pathology that can be used for dental education. ColorMapEditor offers infinite possibilities to adjust and add options for the optimisation of virtual teeth.

**Discussion**
Virtual teeth have unlimited availability for dental students, allowing them to practise as often as required. Virtual teeth can be made and adjusted to any shape with any type of pathology. Further developments in software and hardware technology are necessary to refine the ability to colour and shape the interior of the pulp chamber and surface of the tooth to enable not only treatment but also diagnostics and thus create a greater degree of realism.

**Conclusion**
The creation and use of virtual teeth in dental education appears to be feasible but is still in development; it offers many opportunities for the creation of teeth with various pathologies, although an evaluation of its use in dental education is still required.
INTRODUCTION

The use of virtual reality (VR) is becoming increasingly common, as illustrated by the extensive use of computer games and use of VR software in fields such as architecture to create 3D (three-dimensional) designs.1 VR was first used in medical education approximately 15–20 years ago.2,3 In dentistry, for example, VR combined with haptic feedback was used to simulate drilling in a jawbone and to insert an oral implant.4 Since 2003, the ACTA (Academic Centre for Dentistry Amsterdam) has experimented with VR. VR was introduced to the dental education programme at ACTA in 2010.

In the contemporary pre-clinical simulation laboratory, students practise on extracted human teeth combined with plastic teeth in a typodont and a phantom head. The accuracy and precision of non-clinical testing of dental students’ proficiency in crown preparation on a typodont has been evaluated. This analysis showed that performance on typodonts is a poor predictor of clinical performance on patients. Students performed worse on the clinical crown examination than the typodont examination.5 Experience has shown that in many countries, the number of suitable extracted teeth available for dental education is insufficient. In most dental schools, extracted teeth must be sterilised before use, which may cause potential hazards and negatively affect their quality. Plastic teeth look and feel very different from natural extracted teeth and usually have no simulated pathology; those that do exhibit some pathology are very expensive.6–8 Furthermore, typodonts may easily become contaminated, putting students and teachers with airway problems at risk.9

Virtual teeth in a virtual learning environment can offer many solutions and opportunities in dental education. For example, pre-surgical practice in a virtual environment using a 3D model of a virtual tooth generated from an original CBCT was shown to improve endodontic microsurgery performance.10 The availability of virtual teeth is unlimited, they can be more realistic than plastic teeth, there are no costs for the students as there are with plastic teeth, and they are safe to work with in terms of hygiene and patient safety. Virtual teeth can be created in any quantity and can display any type of dental pathology for a virtual patient case.

Virtual teeth can be used in a simulation learning environment, such as the haptic dental trainers Simodont®, PerioSim™ (University of Illinois, Chicago, USA) or hapTEL™ (Kings College London, University of London, UK). Together with Moog Inc. (Nieuw-Vennep, the Netherlands), the ACTA developed the Moog Simodont dental trainer (Simodont), a device used to train dental students (Fig. 1). The Simodont consists of a training console and a computer. The training console consists of two instruments and a small screen (800 × 600 pixels) located in the position of the patient’s head. Under this screen, two instruments are attached to the simulator. One instrument is shaped as a dental handpiece and provides haptic feedback, and the other serves as a dental mirror. Thus, when a virtual tooth is cut, visual, audio and tactile feedback are received simultaneously. ‘Haptic’ means relating to or proceeding from the sense of touch.11 The amount of force feedback received depends on the dental tissue being
‘treated’; enamel feels harder than carious tissue. A 3D view is created using special glasses. A separate computer connected via an interface to the training console contains the lesson program for the students (i.e. the courseware). The courseware contains a ‘waiting room’ of virtual patients with virtual teeth and manual dexterity assignments.

This study describes the development, creation and uses for virtual teeth with and without pathology in dental education. It provides dental educators with insight into the procedures involved and in the development and possibilities offered to help them develop their own ideas about creating a virtual learning environment and virtual teeth.

**Fig. 1.** Moog Simodont® dental trainer

**MATERIALS AND METHODS**

**Figure 2, step 1**
The creation of a virtual tooth begins by scanning an extracted tooth with a cone beam computer tomography (CBCT) scanner. In this case, a NewTom 5G (QR SLR, Verona, Italy) was used. The resolution was 0.2-mm isotropic voxels. The scan data were processed using Amira software (Visage Imaging, San Diego, CA, USA), version 4.2, to produce a Digital Imaging and Communications in Medicine (DICOM) file containing data describing one tooth. The complete file consists of multiple 2D (two-dimensional) grey-scale images.
The software program ColorMapEditor® (CME), which was developed by Moog based on the Sensegraphics (Stockholm, Sweden) toolbox H3D, was specially designed to display and edit the file representing the scanned tooth. CME is an application used to create and edit a ‘lesson’ for the Simodont simulation software. In a lesson, many files and different volume data are combined to specify, for example, a virtual jaw with a virtual tooth (Fig. 3). With CME, a user can create and modify volume data and colour data, load a tooth, place the tooth in a jaw and build a virtual mouth, that is, a virtual patient, for dental education.

To begin creating and editing a virtual tooth, the DICOM of the scanned tooth file must be loaded in CME and saved as density data. The density data represent the hardness of the various tooth materials (enamel, dentine, pulp, etc.). The next step is to derive a colour data file from the density data. This is a separate file in which colour is added to a certain voxel (a volumetric pixel), saved in three dimensions and shown in 2D slices or as a 3D image when the complete tooth is shown. The third file needed to load the tooth is the iso volume file, a separate file that determines the shape of the outside surface of the tooth using an iso value. ‘Iso’ is a term used to define a value that connects voxels with the same grey value on the 3D volumetric model.

The colour data, density data and iso volume are saved as nrrd files (nearly raw raster data). The combined iso volume and density data form a snapshot, a separate file that is saved to allow the simulator to read both files to create a single complete image. All of these files (density, colour and iso) are separately saved to create many possibilities for editing the tooth; for instance, the density of the tooth can be edited without deforming the surface and thus the shape of the virtual tooth.

Fig. 3. Virtual lower jaw
Chapter 2  |  Creation of virtual teeth for dental education

Figure 2. Six steps for creating a virtual tooth (27) with pathology in CME.

1. Scan a tooth (CBCT)

2. Start editing in ColorMapEditor

3. Select a (normalised) iso value to create the surface of the tooth

4. Edit the file in 3D by changing the density and adding mass

5. Colour the inside of the tooth
6. Colour the outside of the tooth

7. Finish

**Figure 2, step 3**
The file representing the scanned tooth contains more density data than exclusively the data of the tooth. Some of the reflections of the x-rays are also read as density data. When defining the shape of the tooth, the boundary between ‘air’ and ‘tissue’ must be determined; this is based on the iso value, a normalised value between 0 and 1. Before determining the iso value, the range of the density data in the file should be set to the limits of the data to ensure that all of the density data in the file can be used. The value is selected by trial and error. If the iso value is too high, many voxels from the scan will be excluded from the surface of the tooth, and the projected image will contain ‘holes’. If the iso value is too low, too many voxels from the scan will be included, the shape of the tooth will be deformed, and the pulp space will not be hollow. Once the correct iso value is selected, the surface of the tooth can be edited.

**Figure 2, step 4**
The iso surface is derived from the density data file. To edit the surface, virtual mass must be added to the density data file of the tooth, and the iso surface (shape of the tooth) must be derived from this file.

When the surface and shape of the tooth are established, the iso surface can be saved. After determining the iso surface, the density data can be adjusted. These adjustments make it possible to create soft, virtual carious tissue with a value below the normalised iso value. Very soft virtual tissue can be added to the tooth without altering its outside shape. A haptic device, the PHANTOM Omni (SensAble Technologies, Inc., MA, USA) was used to add virtual 3D mass to the tooth. The Omni makes it possible to feel the outside surface of the tooth and the cavity using force feedback.
During the scan of the tooth, faults or artefacts can occur in the scan file. These virtual voids in the density data can be corrected by adding virtual tissue.

**Figure 2, step 5**  
When the shape of the tooth is determined, pathology is added at the correct density (which translates into a specific hardness); adding colour to the tooth completes the 3D image and adds more realism. The nrrd file for the colour data consists of grey values that show the different tissues (i.e. enamel, dentine, pulp, caries) for colouring. The colour is added to the tooth in both the 3D and 2D images. In the 2D image of the virtual tooth, colour is added on three axes: the x-axis, y-axis and z-axis. The tooth is divided into thin slices that are 0.2 mm thick, which makes it possible to select a very specific voxel in the tooth and add or adjust the colour. The selected RGB (red, green and blue) value defines the colour; this value is between 0 and 255. The RGB value must be determined for every tissue that is coloured (enamel, dentine, pulp and caries). Two different sets of RGB values for one specific colour, that is, two different shades of one colour, are used. This gives more depth to the colour and thus the different tissues of the tooth. The tooth is coloured by filling individual voxels or a set of voxels with the selected colour.

**Figure 2, step 6 and 7**  
To finish the outside surface of the tooth, the PHANTOM Omni, a pencil with force feedback, is used. This makes it possible to colour the tooth very precisely. The outside surface of the tooth can be made ‘magnetic’ so that the pen gives constant force feedback.

When the virtual tooth file has been completed, the virtual tooth can be placed in a virtual jaw. This complete lesson, consisting of a virtual jaw and virtual teeth, is used in the simulator to enable the treatment of a virtual patient (Fig. 3).

**RESULTS**

The procedure described above offers many possibilities for the creation and editing of virtual teeth to be used in a virtual learning environment for dental education. CME is a new software application and is easy to use, to create and edit virtual teeth. The virtual teeth can then be used to execute a treatment in, for instance, Simodont. The creator of the virtual teeth can decide what shape, hardness (density), colour or pathology will be added to the virtual tooth. To date, a digital library (Fig. 4) of 55 virtual teeth, including both adult and deciduous teeth with and without pathology (Fig. 5), is available at ACTA and accessible to any school upon request.
Fig. 4. Examples of virtual teeth in the digital library.
Figure 5. Examples of virtual teeth

Sound teeth

Tooth with extensive decay

Deciduous tooth

Maxillary Incisor
DISCUSSION

The use of CME to create virtual teeth allows the adjustment of the appearance, shape, mass and hardness of the tooth in a scan. A portion of the tissue of a scanned tooth with caries may be missing in the file because the cone beam CT does not detect all of the caries, which has a low density, in a large cavity. In this study, virtual teeth are obtained from a scan made with a CBCT device. Another study demonstrated the possibility of obtaining data using micro-computed tomography. This possibility was also tested in this study, but micro-CT provided a file containing too many data, with a resolution that could not be used in the computer of the simulator. Additionally, this high resolution did not improve the level of realism of the virtual tooth when projected in the Simodont. With CME, it is possible to build up the density, reshape the surface and create virtual caries in the tooth. Students can learn to remove caries while using the colour or staining of the caries, if a tool such as the caries detector is applied or the hardness of the decay is used as a guide. Dentists feel the hardness of the tooth to locate the region in which they are cutting. The model of the density data is therefore very important when the tooth is used for cutting or removing caries to increase the realism of the treatment.

In a virtual tooth, a composite or amalgam restoration can be designed with the required shape, colour and hardness, which allows dental students to practise how to shape, finish and remove a restoration.

Further development of CME is necessary to optimise the image of the virtual tooth. For example, to make the appearance of the tooth more realistic, it will be necessary to add texture to the surface, that is, change the light reflection of the surface to make the enamel and root appear different. Additionally, the option to create white spot lesions on the virtual teeth contributes to a realistic appearance and enables additional diagnoses. Developing an option to colour the inside of the pulp chamber in virtual teeth will create the opportunity to prepare for an endodontic access cavity and locate the canal orifices. Further research is recommended to evaluate the use of virtual teeth in dental education. The introduction of a new virtual learning environment with virtual teeth raises questions, such as whether the teeth appear sufficiently realistic to serve its purpose in dental education, which must be answered before acceptance in the curriculum can be possible.

The use of extracted human teeth in dental education remains the optimal basis for the clinical training of dental students in many aspects, for example, to provide the realistic feeling of drilling and instrumentation. However, the difficulties in accessing a sufficient number of suitable extracted teeth for all students, issues with hygiene and the ethical questions involved in using human material for educational purposes without written consent make the use of virtual teeth very attractive. Virtual teeth offer many advantages and opportunities to overcome these problems and can be used as an additional learning environment in contemporary dental education. The impact of the use of VR on the performance of endodontic microsurgery
was evaluated in a previous study. These authors used virtual teeth based on CBCT scans from a cadaveric porcine mandible.

The virtual teeth provided different force feedback in various tissues based on their density values. The virtual teeth in this study were not coloured, and they were not created to be a substitute or addition to actual clinical settings, which is the purpose of the current study.\textsuperscript{10} The creation of realistic looking virtual teeth with and without pathology offers the opportunity to present students in an early stage of education in the simulation laboratory with a realistic clinical problem, a patient with diseased teeth, instead of only plastic teeth or extracted natural teeth. Using a virtual learning environment with virtual teeth offers the chance to practise in a highly realistic and safe environment. In contemporary dental education, every student practises on his or her own collected extracted teeth. This makes it almost impossible for the university to ensure that every student receives the same pre-clinical education and acquires the same practical experience. Plastic teeth are expensive for students and universities to buy, and the hardness of the material is usually not comparable to that of real teeth. However, this is not the case with virtual teeth. Moreover, when using virtual teeth, assignments for students are standardised, which makes it possible for teachers to provide standardised feedback and for students to exchange treatment plans and discuss patient cases. In addition, during clinical simulation tests with the use of virtual teeth, the testing environment is identical for every student, which eliminates differences in the difficulty of the tests; this standardisation is impossible when extracted teeth are used. In virtual cases, every student treats the same patient and treats the same virtual tooth and pathology.

The projection of the virtual teeth by the two beams in Simodont produces an image with a limited resolution. Thus, in addition to the virtual teeth, photographs of the scanned teeth are still necessary for accurate diagnosis and should be incorporated in the courseware and lessons. At the moment, it is not possible for every tooth in the virtual jaw to be haptic and fully rendered. The computer that secures the haptic rendering has limited memory. Additionally, the graphics card of the computer limits the number of triangles that can be displayed to create the 3D image of the virtual tooth. The solution to this problem is to use Accutrans\textsuperscript{®} 3D (version 2.12.1) to create a low-resolution model of all the teeth in the jaw that are not involved in the treatment of the virtual patient. Low-resolution models are made for both the haptic and colour models. A low-resolution haptic model consists of approximately ± 1000 triangles, while a low-resolution image of the graphic model consists of approximately ± 10 000 triangles. These low-resolution models project the image of a virtual tooth, and when touched with instruments, they give haptic feedback. However, it is not possible to make a preparation in the low-resolution teeth. It is currently possible to create a jaw with three or four haptically rendered teeth. When creating a lesson in the simulator, the CME user can decide which teeth should be fully rendered and haptic and which teeth should be visible in a low resolution format, depending on the virtual patient case.
The aim of using virtual teeth in a virtual learning environment in the curriculum, in addition to the use of plastic teeth and human extracted teeth, is to make the transition from the contemporary pre-clinical laboratory (with phantom heads) to the clinic (where real patients are treated) more natural.

**CONCLUSION**

The use of VR has become an important and permanent component of medical and dental education. The creation and use of virtual teeth in dental education has contributed to this development. The creation of virtual teeth with and without pathology offers many opportunities and advantages for dental education in terms of safety, cost and usability. CME is a very versatile and useful application for creating and editing virtual teeth. It is continually updated to improve and expand the possibilities for creating virtual teeth. This enables the opportunity to let students work on a variety of pathologies in virtual teeth and even to develop complete patient settings with varying degrees of complexities, allowing dental students to develop competencies and skills that would otherwise require patients or extracted teeth, which may not be sufficiently available in many dental schools. Further research is necessary to evaluate and validate the application of virtual teeth in dental education.
REFERENCES