

## Endodontic Simulator for Training the Access to the Pulp Chamber and Root Canal Preparation Tasks

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**Abstract**—This paper describes a Virtual Reality simulator to perform dentist training in tasks such as the access to the pulp chamber and the preparation of root canal. The simulator consists of a haptic device adapted to simulate the instruments used in dental procedures, a virtual environment simulating the interactions between the haptic device and the tooth being treated and a visualization tool of the simulation.

**Keywords:** Dental training; haptic device; virtual reality in health training.

### I. INTRODUCTION

The process of training students in dentistry requires them to repeat the same tasks numerous times in order to master the techniques to be employed, before being placed ahead of real patients. This training can be performed in animals, cadavers or extracted teeth. However, there are several ethical problems involved in obtaining these materials, beyond the difficulty of obtaining teeth with the desired anatomy. An alternative are the plastic teeth, however, the uniform composition of these artifacts prevents the student to identify the layers of enamel, dentin and pulp that form the tooth, and apply the correct force to remove each material [14]. Moreover, in both types of teeth it is not possible to place the student in specific situations because the available teeth may not have all important features, such as teeth with internal calcification, multiple roots or irregular shaping.

In order to minimize the ethical problems involved in getting teeth for training and allow the student to practice several times, some dental educational institutions are using virtual reality simulators [1]. The simulators still allow to produce specific models for each type of training and carry out the actions developed by the students [13].

As dental procedures require precise control of movement and force applied on the teeth, the use of haptic devices in the simulators is very important [3]. Using the adequate force feedback for each situation, it is possible to virtually represent teeth models with every feature needed for training. In addition, it allows all the students to have uniform training.

Endodontics is the speciality in odontology that treats diseases that occur inside the root canals of the teeth. At the beginning of an endodontic treatment, dentists use high speed rotary instruments to make the *Access to the Pulp*

*Chamber (APC)* and then, they use small files to perform the *Root Canal Preparation (RCP)* in order to remove the contaminated tissue from the root canal and widening them, keeping its original anatomical shape. To succeed, the dentist must perform the correct handling of each file to prevent them from breaking or to leave parts of the tooth without treatment.

This work presents a VR simulator that focus on both APC and RCP training tasks. The simulator uses a virtual environment, and a haptic device developed specifically for this purpose, to perform the main tasks of an endodontic treatment. During the simulation, the system records the actions and movements performed by the user so that the user can later visualize the sequence of actions performed and identify possible failures occurred during the procedure.

### II. RELATED WORK

For this work, we analyzed papers published in conferences and journals from both computer science and dentistry areas dealing with VR simulators that aim at training dentists in APC and RCP procedures.

The Moog Simodont Dental Training Simulator [2] is made up of specific hardware and software. With this simulator, the student can visualize the three-dimensional shape of models and manipulate the rotary instruments with high precision. However, its high cost and the need for a large physical space are a hindrance for its use.

In the research field, in turn, simulators have been developed using customized conventional force feedback devices. Some of these use expensive devices such as the Phantom Premium 6-DOF [5] or the Phantom Omni [10]. Both are able to simulate hand instruments for teeth exploitation and rotary instruments to remove tooth decay and APC. Seeking lower cost solutions, Tse et al. [13] developed the HapTEL, a simulator for rotary instruments based on a Novint Falcon haptic device with 3DOF and adapted to capture the rotations of a dental drill. The simulation of rotary instruments is also performed in the simulators proposed by Wang et al. [14] and Toosi et al. [12], which use a Phantom Omni device to simulate APC procedures. Given the characteristics of the Phantom Omni and Novint Falcon devices, these last three simulators do not

provide force feedback to the rotations made with the rotary instruments.

For RCP tasks, in turn, the work of Liu and Li [7] shows a simulation method to perform the interaction between endodontic files and *pulp's teeth*. Another interesting work is the simulator described by Toosi et al. [11]. Not only it allows the user to perform procedures with rotary instruments, but it also allows the execution of RCP using manual files and seeks to simulate the files' curvature when they are in curved canals. However, the simulator does not provide force feedback to the file rotations, which is important to help the user to perceive when the file is stuck in the canal.

### III. SIMULATION DESIGN

The simulator described in this paper consists of a haptic device and a virtual environment to perform the simulation. The system records all movements made with the instruments, the sequence used and other technical data used to identify if the user correctly applied the sequence of steps according to the chosen technique.

#### A. Haptic Device

For this simulator we used a commercial haptic device Novint Falcon with 3 degrees of freedom (DOF). To make the tasks more realistic, we built two handlers/adapters to be plugged to the haptic device. The first adapter is used for holding a dental drill and adds three new DOFs (Figure 1b), allowing the user to manipulate the instrument in the virtual environment with 6 DOF and is used to perform the APC task. The second adapter is used for RCP task and consists of an endodontic file. It provides one additional rotational DOF (Figure 1a) that allows the file to be rotated about its longitudinal axis. The additional degree of freedom also includes force feedback, because the tactile sensitivity of the dentist is of utmost importance during RCP tasks.

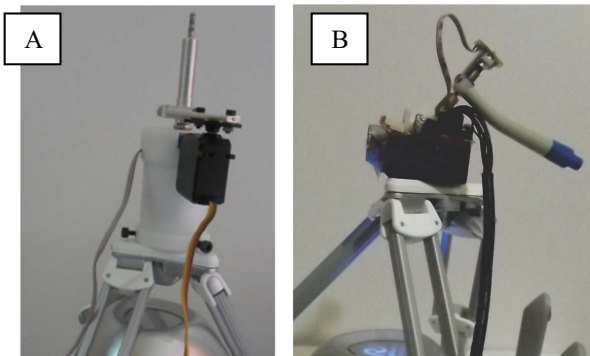


Figure 1. Interaction devices. (A) Endodontic file. (B) Dental drill

#### B. Virtual Simulation Environment

The virtual simulation environment (Figure 2) has three types of objects. The first one represents the virtual tooth that will be treated, the second is a virtual model of the lower jaw and the last one is a rotating tool for drilling the tooth.

The lower jaw is modeled as a set of polygons. The tooth is volumetrically modeled inside an array of 128x128x128 voxels. Each voxel describes both the outer and the inner

structure of the object, identifying the type of material (enamel, dentin, pulp, decay, amalgam) and its specific density, which determines its resistance to wear. The density of the voxel is reduced according to the contact between the tool (*drill bit or file*) and the voxels of the tooth, until they are removed from the model, i.e., when its density reaches zero. The force feedback calculation for haptics *render* is performed with an adaptation of the method presented by [9] and detailed in [3]. The graphical rendering of the tooth being treated is performed using a *Marching Cubes algorithm* [7] that runs on the GPU.

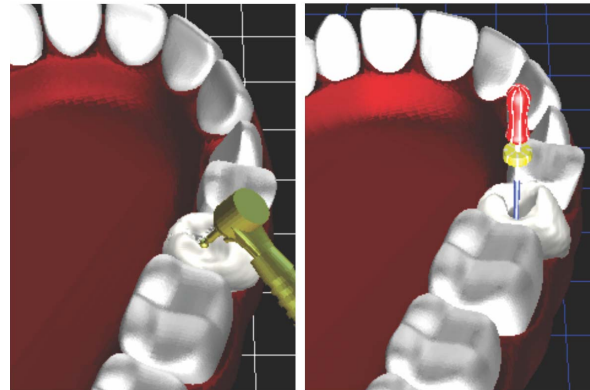


Figure 2. Virtual Environment. Left: Dental drill. Right: Endodontic File

The active part of the tool is also volumetrically modeled inside a 3D array of 11x11x80 voxels, which is used in the haptic rendering for handling collisions between the voxels of the tooth and the dental tool. Figure 3 shows an example of a file and two drill bits with their active and inert parts.

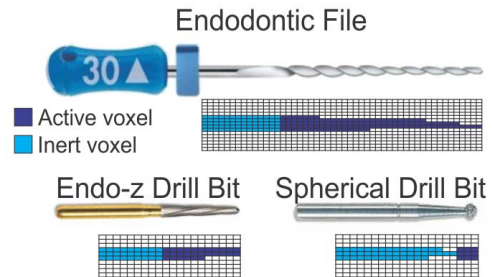


Figure 3. Dental Tools and its Active and Inert parts

### IV. THE SIMULATION

The simulation is split into two parts. In the first one, the user must perform the APC task, while in the second the RCP task is performed. In both steps there are secondary procedures that should be performed in order to complete the simulation, although they do not require simulation.

#### A. Secondary Procedures

In this simulator, the secondary procedures are performed using pre-processed animations that are activated by the user whenever he deems appropriate. Preliminary procedures executed by the simulator are: anesthesia, rubber dam isolation, irrigation/aspiration, odontometry, X-ray and temporary filling.

## B. APC Procedure

The APC is performed using the handler that possesses an attached dental drill. We use two kinds of drills for this task (Figure 3). A spherical drill bit to make a small opening in the tooth crown towards the pulp chamber, and then a conic Endo-z drill bit to remove all the enamel and dentin of the roof of pulp chamber, allowing endodontic instruments to be used without interference. The correct application of pressure on the instruments and the direction chosen for the opening are the factors to determine the success of this part of the treatment.

The result of treatment should be a visible pulp chamber allowing the user to visualize small holes generated by the opening of the tooth canals.

## C. RCP Procedure

For the RCP task, the handler which has an endodontic file (Figure 3) attached is used. In the beginning of the RCP task, the user must perform the odontometry, which consists of measuring the distance between the crown and the tip of the tooth root by means of an X-Ray image. After the measurement, the user must specify one or more cursors in the file body, in order to set the length of labor, and thus prevent the root of the tooth to be drilled and reach the gums.

Hereafter, the user must remove the material inside the tooth channel by applying rotational and oscillatory movements to the file. These movements will both enlarge the channel and remove the contaminated tissues.

## V. TOOL TO VISUALIZE THE SIMULATION

After the simulation it is possible to see the sequence of actions performed by the user within the system. Figure 4 shows the actions performed by the user during the RCP task. The upper graph illustrates the vertical movements performed with the files. In the middle of the screen the graph represents the rotation and oscillatory movements, and the bottom part displays a list of the sequence of actions taken.

## VI. CONCLUSION

The simulator described in this paper can help students to repeat the training several times without missing material. In addition, all students can receive uniform training using models of teeth that are not normally available. During the simulation, the system stores all the actions taken by the user and, by the end, it allows the user to visualize these actions and check if the techniques were properly chosen for the clinical case presented. In preliminary tests conducted with users, they emphasized that the visualization tool is great for monitoring instrumentation sequence and allows identifying if the tooth was fully treated.

## ACKNOWLEDGMENT

Our research is funded by the National Institute of Science and Technology in Medicine Assisted by Scientific Computing (MACC) (Grant CNPq 181813/2010-6 and FAPERJ E-26/170.030/2008).



Figure 4. Sequence of actions performed during the simulation

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