Evaluation of a Haptic Virtual Reality Simulator for Endodontics Training

Tales Bogoni
Mato Grosso State University
Medicine Assisted by Scientific Computing
tales@unemat.br

Márcio Pinho
Pontifical Catholic University of Rio Grande do Sul
Medicine Assisted by Scientific Computing
pinho@pucrs.br

Roberta Scarparo
Pontifical Catholic University of Rio Grande do Sul
roberta.scarparo@pucrs.br

ABSTRACT
The usage of haptic simulators in Odontology has been growing in recent years. With them, users can employ rotational instruments attached to force-feedback devices to achieve various manoeuvres atop a simulated tooth. There is, however, one speciality within Odontology, called Endodontics, for which no simulator exists. Endodontics is responsible for treating diseases affecting the roots of the teeth. This procedure demands of the surgeon fine motor skills and an accurate sense of touch. Aiming at improving these professionals' training, this work has developed and analysed the application of a haptic simulator designed for the practice of the RCP routine with manual files. As reported by tests carried out with specialists, the simulator is sufficiently realistic to mimic such a task.

Categories and Subject Descriptors
• Applied computing~Interactive learning environments

General Terms
Interactive Learning, Human Factors, Haptics

Keywords
Virtual Reality. Endodontic Simulator. Haptics.

1. INTRODUCTION

The traditional odontology teaching model [2] for the field of endodontics goes through 3 stages: the **theoretical** stage, in which the student is given conceptual bases about the treatment; the **pre-clinical** stage, in which the student utilises a laboratory and dummies for practising and acquiring technical and motor skills; and the **clinical** stage, in which the student makes direct contact with the patient.

One of the issues with this training emerges during the pre-clinical stage, in which either human or resin-made teeth are used, embedded in dummies or hand-manipulated by the student. Whichever variety is chosen, the learning process will be obstructed. With respect to actual human teeth, there are few units that meet the necessary requirements and it is not possible to reproduce treatment among numerous students. When it comes to resin teeth, on the other hand, the homogeneous material that composes their interior represses any tactile sensitivity to the unique resistance posed by the distinct materials of which a real tooth consists -- such as enamel, dentine or the pulp --, thus preventing learners from employing the correct amount of force necessary for the removal of each material. In addition, both kinds of teeth may disable students from being subjected to certain specific situations, as the teeth at their disposal may not have the necessary morphological characteristics for perfecting their studies.

Considering the obstacles presented by the traditional training method, the usage of three-dimensional (3D) simulators may prove an alternative to improve students' skills. This asset allows training to be performed uniformly and with greater amount of repetitions. Moreover, using simulators as a complement to traditional training enables the student to access a greater range of situations that can be difficult to experience in the real world. For this end, haptic devices are adopted.

In this context, this work has designed a haptic simulator for endodontics that allows, among other tasks, for the execution of Root Canal Preparation (RCP) routines using manual files. Before adopting a simulator as a teaching tool, however, it is necessary to assess its ability to simulate tasks for training. To this end, this paper presents the evaluation of a simulator equipped with a haptic device designed for.

This paper is divided into 6 sections. Section 2 presents basic concepts concerning endodontic treatment. In section 3, work regarding the use of simulators in endodontic treatment is described. Next, section 4 portrays the characteristics of the evaluated simulator. Section 5 describes the methodology put to use in the evaluation and results obtained from tests with users are displayed. Finally, section 6 presents conclusions and future work.

2. ENDODONTIC TREATMENT

In essence endodontic treatment is divided into 3 stages. Firstly, **access cavity** is performed, when rotating instruments are used to remove the enamel and dentine layers, allowing for root canal access. In the second stage, called **RCP**, small calibre manual tools -- named manual endodontic instruments or endodontic files -- are employed. In specific circumstances, they can be replaced by rotating instruments, provided that the dentist is highly experienced in operating such equipment. This stage is responsible for extracting the dental pulp and widening the root canals, removing thin dentine layers. This requires the dentist to

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manipulate the endodontic files in the appropriate manner, so as to prevent them from breaking or leaving portions of the tooth untreated. The third stage is denominated **filling**, which consists of having the dentist fill the root canals with a given kind of filling material and the cavity can be sealed with either a filling or a crown.

During RCP procedures, to perform cleaning up and root canal shaping, dentists must choose the appropriate instrumentation technique to be utilised, which will depend on the clinical characteristics of the tooth being treated. For each instrumentation technique, files must be selected and the dentist's designated course of action must be adequate. This process is called **instrumentation sequence** and is of paramount importance for the success of RCP.

3. RELATED WORK

In the field of evaluating interaction methods, Min Li and Yun-Hui Liu [3] introduce tests with new simulation methods for the interaction of endodontic files with dental pulp. The principal goal of this work is to establish the force applied on the files during treatment and to realistically simulate the pulp's behaviour and the file's elasticity. Another work in endodontics is described by Marras and colleagues [4] and looks to simulate access cavity with rotating instruments. Also on the access cavity procedure, Suebnukarn and colleagues [7] use two haptic devices in one simulator: one to manipulate the rotating tool and another for the odontological mirror, allowing for indirect visualisation of the tooth. This work features results to tests performed with odontology students, demonstrating an increase in the accuracy of their treatment after using the simulator.

On developing haptic hardware, Erikson [1] describes a new haptic device with 6 degrees of freedom (DOF) for perforating teeth. Tests with users have shown the device's ability to convincingly mimic teeth perforation and that the simulator can potentially be used as a teaching tool. Another variety of hardware is described by Tsao and colleagues [8], who planned to ascertain an endodontic file's curvature when placed inside a root canal, as well as the force applied by the user during the execution of kinematic motion.

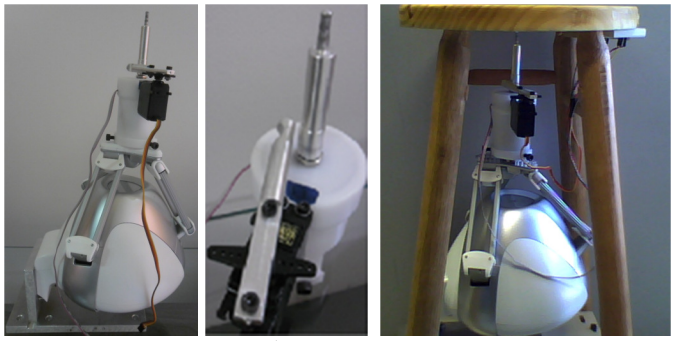
From the bibliography gathered here, it was not possible to locate published works that propose simulating the root canal cleaning and shaping task using manual files.

4. THE SIMULATOR

The simulator developed for this project is composed of a Virtual Environment (VE) that simulates the major procedures involved in RCP. Interaction in the VE is accomplished via a haptic device with 4 DOF.

The haptic device utilised is a 3D Novint Falcon Controller joystick, capable of 3-DOF translation. In order to allow the user to interact with the VE, simulating an orthodontic file, it was necessary to adapt the joystick by attaching a handle similar to an endodontic file's and, thus, create an additional DOF corresponding to the file's rotation (Figure 1a).

For the haptic device's adaptation, a file rotation tracking mechanism was installed, as well as a brake system (Figure 1b), which is in charge of making the rotation movement heavier or lighter. This is necessary due to less force being required to rotate the file when placed loosely inside the canal than when tightly.



a b c

Figure 1 - The Haptic Device

In order to make the handling of the haptic device similar to the way dentists usually operate, it was imperative to have it lie vertically and to mount it on a stand on which the user could support their hand during simulation (Figure 1c). Such a stand serves as support for the dentist's fingers, making the simulation more realistic. In a real situation, the dentist would carry out treatment while supporting their fingers on teeth by either side of the one being treated and making small lateral and rotatory movements with the file.

The VE of the simulator provides for the execution of procedures prior to RCP, the treatment itself which can be carried out, the latter using files of various sizes and tapers. The system also enables the user to perform post-preparation clinical procedures such as re-sealing the tooth. During the course of simulation, the system records the user's actions and, at the end, displays the instrumentation sequence used and the actions preformed during PCR.

5. EVALUATION

The methodology put into practice to evaluate the simulator consisted of carrying out empirical tests to which endodontics specialists were invited, including lecturers, experienced professionals and students who had previously undergone endodontics courses. The sample was composed of 12 individuals, of which 2 were lecturers, 4 were students and 6 were specialist dentists.

To evaluate the results, the methodology known as 'face validity' [5] was applied a questionnaire to comprising the judgement of whether or not a tool is capable of simulating what is expected, i.e. whether or not it is realistic. In this kind of validation, subjective research is carried out by proposing a questionnaire to users.

In the questionnaire, 5-point Likert scales were used, of which two points were negative (1-bad and 2-regular or 1-not similar and 2-somewhat similar), one was neutral (3-fair or 3-similar) and two were positive (4-very good and 5-excellent or 4-very similar and 5-indistinguishable). For the analysis of the results, each item's frequency was used as metric, having questions classified according to the most frequent answer, known as statistical mode, as described by Rubin and Barbbie [6].

We evaluated aspects to the simulator's realism, both graphic and haptic and the learning time to the use of the simulator.

Figure 2 presents a graph with the distribution of grades given by users on matters related to the realism of graphic models. Compiling these results shows that all items were rated positively, bearing greater incidence of grades 4 and 5.

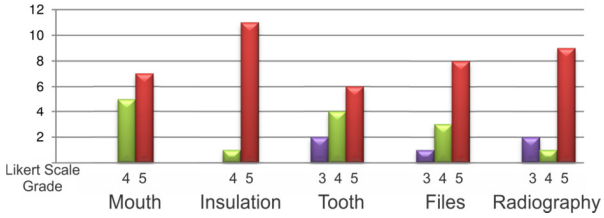


Figure 2 - Graphic models realism

Regarding the perception of different levels of stiffness to the file's touch during kinematic motion, the following topics were gauged: file collision with the outer walls of the teeth, file penetration into the canal, oscillatory and rotatory movements and back-and-forth motion. Figure 3 illustrates the statistical mode for users' replies, portraying the predominance of grade 5 on two of the topics and of grade 4 on the other two. That is, the prevailing grades for all assessed items were positive.

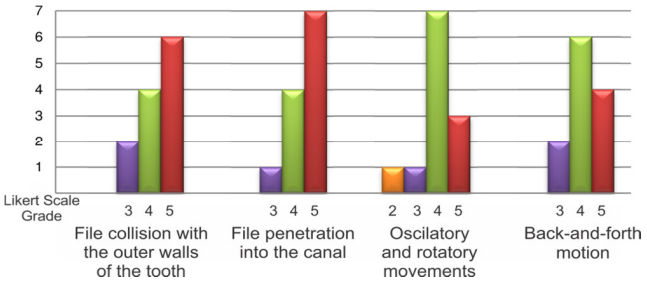


Figure 3 - Perception of contrasting resistances

Concerning similarity with reality, items assessed were: file collision with the outer walls of the teeth, file penetration into the canal, oscillatory and rotatory movements and back-and-forth motion. For these topics, tests participants assigned a grade from 1 to 5 following a Likert scale, regarding 1 as 'nothing similar' and 5 as 'indistinguishable'. Figure 4 summarises the statistical mode of users' answers, showing grade 4 as the most frequent in all assessed topics.

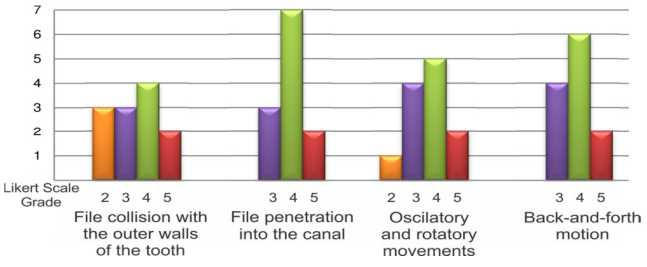


Figure 4 - Haptic feedback similarity with reality

Concluding the evaluation of the simulator, an open question was proposed for users to state their opinions on the application of the simulator as a teaching tool for pre-clinical practical activities. In these answers, 100% of the users considered the simulator to be a good teaching tool.

6. CONCLUSIONS

Currently, scarcely any odontology teaching institutions utilise Virtual Reality simulators in training dentists during the pre-clinical stage. In endodontics, this issue is all the more severe due to the complete absence of simulators capable of mimicking the operation of manual files. Usage of such simulators can minimise the impact of the insufficiency of natural teeth and provide uniform training for all students.

This works presented an evaluation of a simulator designed for the practice of cleaning and root canal shaping routines using manual files. According to the users' answers to questions posed after empirical testing, the simulator can be regarded as sufficiently realistic to mimic the use of manual files.

For future work, the simulator is intended as the training instrument for a regular class of students. This training will allow the student to practise for longer periods than in traditional methodology and will not require a teacher's side-by-side supervision. With this kind of training, students are expected to carry out the RCP task in a speedier fashion, as well as deliver a final result of finer quality.

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