Research Article

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An Innovative Application of Haptics Technology to Reduce Iatrogenic Errors in Operative Dentistry – A Novel Idea

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ABSTRACT

Introduction: *As much as hand-skills are important in Dentistry and Dentist go through so much skill based training, iatrogenic errors do happen sometimes especially in operative Dentistry. Such errors lead to unintended consequences such as pain and discomfort for patients putting Dentist-patient relationship at stake.*

Purpose: *The aim of this paper is to explore if an innovation Haptic technology could address such errors.*

Discussion: *An innovative idea called Haptic Feedback Processing Unit (HFPU) is proposed. HFPU is an external unit that constantly monitors actual preparations made by Dentist with pre-loaded ideal preps to provide wireless feedback through micro-vibrations in Dentist's index finger. The idea is developed and discussed in detail including various components of HFPU, its functions, communication path and decision making process. HFPU designed as an enabler to Dentist's dexterity and it is not meant to replace or take over operative procedure.*

Conclusion: *This manuscript presents this innovative idea as the one with a promising future to avoid or reduce iatrogenic errors in operative dentistry. Further development and testing could drive this from drawing board to real world.*

Keywords
Innovation in dentistry, Haptics in Dentistry, reduce iatrogenic errors, reduce dentist induced errors, improve Dentist-patient relationship.

Introduction
According to American Dental Education Association (ADEA), a dentist must be adept at working with precision on an extremely small scale with superior eye-hand coordination to ensure patient safety and integrity of the profession [1]. The importance of hand skills is most pronounced in operative dentistry involving intra-coronal restorations such as fillings. Although a Dentist is professionally trained on hand-skills, sometimes errors induced by dentists are inevitable causing discomfort to patients which makes ideal restoration a challenging task for a Dentist. This paper explores an innovative approach to address iatrogenic errors in operative dentistry which could reduce unnecessary pain and discomfort for the patients.

Errors in Operative Dentistry
When doing cavity preparations, damage on tooth surfaces adjacent to approximal restorations is one of the critical errors in operative dentistry [2]. Due to vibration of rotating tools such as dental hand piece that are not well center or if they are used for a long time might cause painful sensation to patients. Over-extension of the carious lesion can cause perforations of the pulp cavity which might lead to unnecessary treatments. In addition, over-extension of cavity preparation could cause the cusps to weaken fracturing the filling. Under preparation of the cavity, on the other hand, could cause incomplete removal of caries or result in shallow cavities with in-sufficient material strength leading to filling breakage due to a bite.

Haptic Technology
The word haptics pertains to both perceptions of touch (or tactile feedback) and force (kinesthetic feedback) [3]. Haptics is a bi-directional sensory modality involving simultaneous exchange

of information between human and the environment which can provide considerable amount of information to the individual about the surrounding environment [4]. One can distinguish and recognize objects, even without seeing them through haptic perception of sense of touch [5].

Interaction with computer has been enhanced through integrating haptics with sound and graphics to give the user a sense of action and properties of on-screen objects [4]. Haptics is an emerging field which is organized into four sub-areas; human haptics, machine haptics, computer haptics and multi-media haptics [6].
According to Adulmotaleb et al., the four sub-areas are defined as below [7]:

- Human haptics refers to the study of human sensing and manipulation through tactile and kinesthetic sensations.
- Machine haptics involves designing, constructing, and developing mechanical devices that replace or augment human touch.
- Computer haptics is defined as the art and science of developing software algorithms that synthesize computer-generated forces and tactile stimuli to be displayed to the user for the perception and manipulation of virtual objects via touch.
- Multimedia haptics is the acquisition of spatial, temporal, and physical knowledge of the environment through the human touch sensory system and the integration/coordination of this knowledge with other sensory displays (such as audio, video, and text) in a multimedia system.

Haptics – Mechanism of Action & its Applications

At a fundamental level, a haptic system consists of an input device, a processor and an actuator. As shown in Figure 1, haptics is created by a user generated event such as touch of a screen in mobile phone or moving a joy stick in a gaming console. This event triggers the processor to turn on an actuator or similar device that creates a feedback event such as vibration. This vibration provides a simulation of perception of touch in a virtual setting. In other words, the icon selected with a tap of a finger in a mobile phone is not real but the vibrations from haptic feedback makes it real.

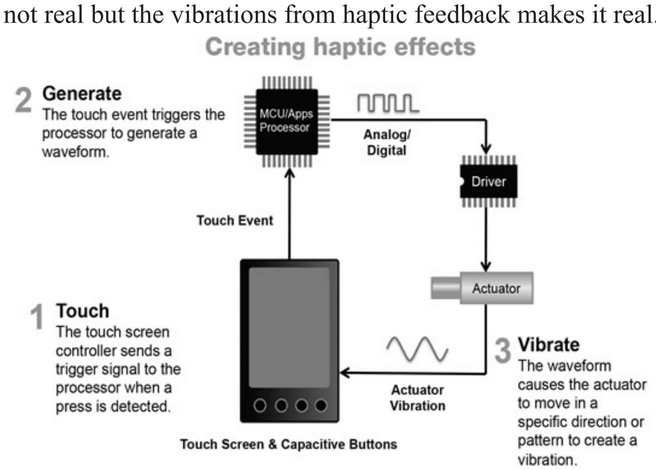

Figure 1: Mechanism of Action of Haptics [8].
Illustration from: Wilson, R. (2015, June 25). Electronics Weekly. Retrieved from Haptics redefine the machine-human interface.

Applications of haptics technology is wide ranging that includes graphic user interface, gaming, scientific discovery and visualization, arts, sound editing, vehicle industry, engineering, manufacturing, tele-robotics, teleoperations, medical simulation and rehabilitation [7]. In the field of dentistry, the use of haptics technology is limited applications such as dental simulators for training future dentists. Such simulators provide simulation exercises for dental students through a combination of haptics and virtual laboratory environment to increase motor skills, student efficiency and reducing faculty time required [9]. DentSim is one such simulators used in dental schools that fully integrates traditional lab allowing students to work on mannequins while viewing their work real-time on a computer screen and to get real-time feedback [10]. Another example is Simodont® software, which is a haptic virtual simulator used to train manual dexterity, cariology, crown and bridges exercise, clinical cases and full mouth simulation experience [11].

Innovative Application of Haptics in Operative Dentistry

Based on data analyzed from the year 2000 to 2008 in the US, more than 250,000 deaths per year are due to medical error [12] and it costed $19.5 billion in 2008 according to a report that analyzed medical claims data [13]. Similar data for dental is more elusive as many state governments failed to keep data related to number of deaths and injuries which to be fair is still a tiny fraction of all dental visits [14]. In a survey of dentist-patient relationship, fear and dislike of the dentist, low confidence in dentist and a poor dentist attitude are associated with poor attendance [15]. This article is an attempt to investigate if haptics technology could be used to alleviate patient pains caused by iatrogenic errors in operative dentistry which could in-turn improve dentist-patient relationship by reducing unnecessary pain experienced by patients. The sections below extend haptics technology beyond laboratory to address the central question of whether iatrogenic errors from operative dentistry be avoided and/or reduced through a haptic feedback guided operative procedure of cavity preparation.

In a conventional operative procedure involving cavity preparation, a dentist uses x-ray images to determine the affected teeth and the extend of carries progression. This sets much of the carries removal procedure where a Dentist's dexterity and hand-eye coordination to drill tooth to remove the carries. In some instances, due to imperfect line of sight, patient movement, limitations of X-ray being two dimensional etc. lead to unavoidable errors of overextension or under-extension of cavity preparations or pulpal exposure. This could cause unnecessary treatment and pain to patients.

In the proposed Haptics aided operative procedure a combination of digital information and computer assisted tactile feedback could reduce the occurrence of such unavoidable errors by acting as a guide to Dentist while performing cavity preps. As shown in Figure 2, in addition to Dentist dexterity and hand-eye coordination, Haptic Feedback Processing Unit (HFPU) enables Dentists to deliver ideal preps. At a fundamental level HFPU tracks the hand-piece movement, compares the profile being created to one of the ideal preps in the library and provides tactile feedback when the profile of the prep deviates from the ideal contour.

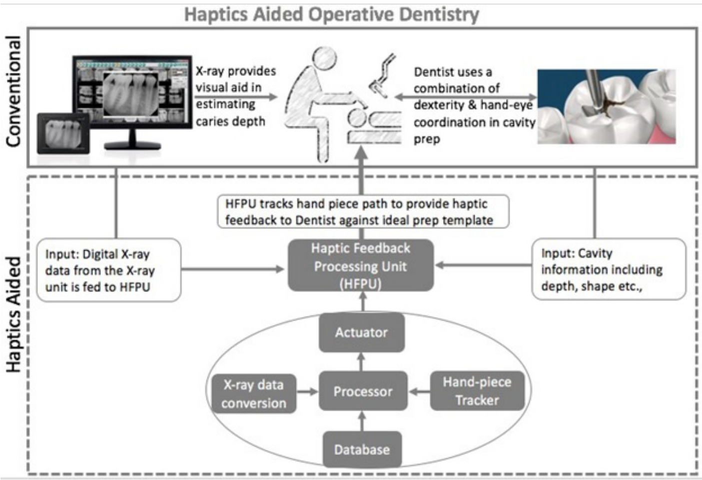

Figure 2: Conventional versus Haptic Aided Operative Dental Procedure.

A detailed description of various components of HFPU is discussed below:

- Processor – This is the brain of the HFPU that processes incoming data from X-ray unit, converts data to information and triggers the actuator to send tactile feedback to the Dentist.
- Actuator – Actuator receives control signals from the processor to wirelessly activate a micro-vibrator in the finger sleeve that the Dentist will wear to get tactile feedback.
- X-ray data conversion – The X-ray images fed by the X-ray unit will need to be converted to binary information. Typical X-ray data-set could be tooth number, dimensions of carries in millimeters, contour of the carries etc.
- Hand-piece tracker – wireless position sensor stuck to the hand-piece tracks the movement and orientation of the bur. This information is fed to the processor which converts the bur movement path cavity profile. Alternatively, a hand-piece fitted with water resistant micro-camera could also serve this function.
- Central Database – secured repository of all things data including ideal morphology of all teeth for both primary and permanent, contour and dimensional information of ideal cavity for all levels of carries progression, collects and stores incoming data from X-ray unit and hand-piece tracker.
- Energy Source – A standard 120 V power source to power various components of HFPU.
- Micro-vibrator finger sleeve – Finger sleeve worn under the gloves is embedded with micro-vibrator that connects via blue tooth to the HFPU to create tactile feedback through micro-vibrations.

The communication between Dentist and HFPU, as shown in Figure 3, happens through Bluetooth to make the interaction seamless and less cluttered with wires. There are two communication path; one involving Dentist and HFPU and the second path is from hand-piece to the processor. The tactile feedback is given to Dentist through micro-vibrator finger sleeve [16], which the Dentist would wear in the index finger under the disposable gloves. The vibrator gets activated from the HFPU actuator via Bluetooth. The path of the hand-piece, which constructs the contour, shape and depth of the cavity preparation, is tracked through position sensor and/or micro-water-resistant cameras. The hand-piece communicates with the processor of the HFPU wirelessly through Bluetooth.

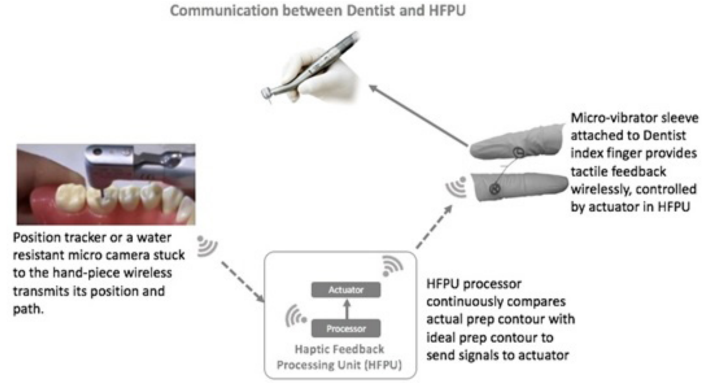

Figure 3: Illustration explaining wireless communication path between Haptic Feedback Processing Unit (HFPU), Dentist's finger sleeve and hand-piece.

Decision tree shown in Figure 4 represents the decision-making process of HFPU. The decision-making process works based on the fact that the communication link between various components of HFPU system (finger sleeve, hand-piece and HFPU processor) is properly established. Once the system is properly communicating the processor constantly checks for the deviation of actual prep with the ideal prep pre-loaded in the HFPU database. If the ideal versus actual prep is within tolerance the system works seamlessly in the background monitoring the prep. If the deviation falls outside of tolerance band, the processor signals the actuator to create micro-vibrations in the finger sleeve. As the Dentist is in full control of the entire process, the feedback can be accepted to correct the cavity prep or it can be ignored. When the feedback is ignored the system goes to idle mode.

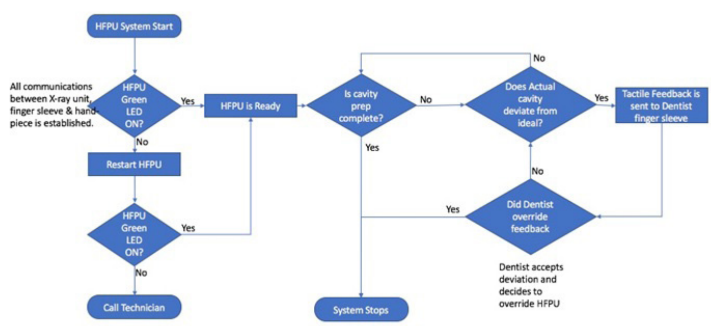

Figure 4: Decision Flow Chart Detailing the Decision-making Logic in Haptic Feedback Processing Unit (HFPU).

Future Implications

This matured conceptual framework of HFPU demonstrates promising benefits to both Dentist and the patient preventing over-extension or under-extension of the cavity preparation that could have unintended consequences. In addition, for young Dentist who are new to the real-world practice could benefit from HFPU as it will help them to gain confidence. Having said that, this conceptual HFPU warrants more effort in design specification, developing proof of concept and testing to validate real-world application. Implementation of HFPU involves inter-disciplinary collaboration between Computer Science and Dentists to fully vet, design, develop and deploy the idea.

Conclusion

Iatrogenic errors are unavoidable during any medical procedure and this is especially true in operative dentistry. This manuscript focuses on the operative dentistry errors during cavity preparation such as under-extension and over-extension of the cavity. The consequence of such error causes unwanted discomfort and pain to patients making the dental visit more unpleasant. An innovative approach to reducing and/or avoiding such errors is proposed through Haptic Technology called Haptic Feedback Processing Unit (HFPU). HFPU complements a Dentist's dexterity by continuously comparing the actual cavity that is being prepared with an ideal prep from the database. The micro-vibrator in the finger sleeve provides feedback if the actual versus ideal deviated beyond the allowable threshold. After thorough discussion of HFPU components, its communication flow and decision tree, it is clear that it could have a promising application in real-world. The Dental community could benefit from this innovative approach and more research and development work needs to be completed to bring HFPU to life.

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