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(REVIEW ARTICLE)

Simulation in dental medicine: Current state and prospects

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Abstract

In medicine, dental medicine and health care, the teaching literature is full of teaching strategies, methods and techniques that serve the teaching and learning of future health professionals. Among these strategies and methods, we find the medical simulation which consists in creating the closest possible care environments to clinical reality using natural, physical, computer or electronic equipment. Its aim is to teach technical and non-technical gestures and procedures for which direct teaching is impossible. In dental medicine, simulation is of unequal importance in the training, development and maintenance of the clinical skills of future practitioners. A large number of modalities have been developed for its uses, ranging from the use of natural teeth, phantom head, computer assisted simulation followed by virtual reality simulation with haptic feedback to robotization.

Keywords: Simulation Training; Education; Dental; Patient Simulation

1. Introduction

In recent decades, parallelly with the technological advances, healthcare simulation has been developed considerably and it has been used as one of the fundamental methods of medical education especially after the publication of the report "To err is human : Building a Safer Health System" in 2000 [1]. It consists of the use of a material (such as a mannequin or a procedural simulator) from the virtual reality or a standardized patient to replicate situations or healthcare environments, for the purpose of teaching diagnostic and therapeutic procedures as well as repeating medical procedures, concepts or decision-making by a health professional or a team of professionals" [2,3]. So, its main goal is to improve the quality and the safety of medical care by supporting the acquisition of psychomotor skills required for actual clinical practice and by providing the students and professionals with the opportunity to repeat gestures and procedures in safe conditions without any prejudice to the patient.

In dental medicine, although that the life-threatening risk is less often involved than in some fields of medicine, the irreversible nature of the majority of surgical procedures and the generalization of the principle of non-invasive dentistry promote the simulation as an essential method in both initial and continuing training of dentists [4]. The first uses of simulation in dental medicine dates back to 1840 since the inauguration of the first college of dental surgery in Baltimore Ohio (USA) [4,5]. Initially, the learning of different dental restoration techniques was practiced on the extracted natural teeth. However, the widespread demand for the use of extracted natural teeth for the manufacturing of dental prostheses at that time limited the possibility to use such a tool in the process of learning. So, faced with this lack of the supply of natural teeth and parallel with the evolution of dental education, Fergus introduced the first

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phantom head simulator in 1894. Since then, simulation in dental education has been progressed and different methods have been emerged [5].

2. Simulation methods used in dental medicine

2.1. Simulators derived from the development of the medical field

2.1.1. High-fidelity mannequins

High-fidelity mannequins like PediaSim [6], SimMan [7] or Resusci-Anne [8] permit the dental medicine learner to learn how to deal with medical emergencies and unforeseen clinical situations that can jeopardize patient's life and harm the dentist reputation. Such simulators imitate different physiological and pathological parameters. They help learners to acquire and ameliorate some skills such as patient protection, upper airway desobstruction, adrenaline injection, stopping an abundant external bleeding, cardiopulmonary resuscitation, defibrillator manipulation.

2.1.2. Simulated/Standardized patients

Although that the concept of simulated/standardized patient training was introduced into medical education in the early 1960s, it was declared in dental education only in 1990 [4,9].

Based on role play, Simulated/standardized patients are a very interesting tool for developing communicational and relational skills needed by future practitioners. Also, they help them to learn how to elaborate meticulous clinical files and how to conduct medical history examination, head and neck examination … [10,4,11,12,13]

2.2. Simulators derived from the development of the dental medicine field:

2.2.1. Natural systems

Natural teeth

These are very effective simulation tools for learning coronary and endodontic preparations, allowing students to develop their tactile sense of different dental tissues as well as developing their gestural skills to understand the different anatomical obstacles (Figure 1). However, they have some limitations that lie mainly in its difficulty of supply and the lack of reproductibility that does not allow an objective and fair evaluation between students. [5].

Figure 1 Simulation using natural tooth

2.2.2. Other anatomical pieces

These are especially animal maxillaries and/or mandibles, partial or complete, that are taken from sheep or pigs corpses. Such simulation permits students to perform incisions and sutures of oral surgery. Its limitations lie mainly in its difficulty of supply and difficulty of storage.

2.3. Physical systems

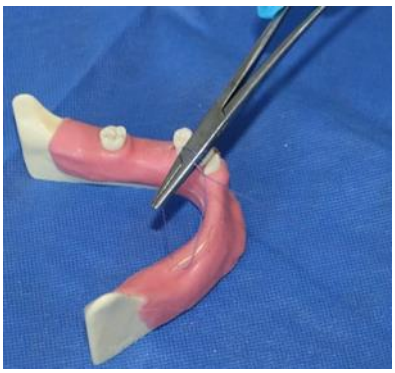
2.3.1. Phantom head patient

It is the basic simulator used in dental medicine education [5] and it consists of a head mannequin with a typodont reproducing the anatomy of the maxillaries, teeth and gum (Figures 2,3,4,5).

Figure 2 Phantom head simulator

There is a large variety of typodonts in the market. They are made up of either plaster, resin or a combination of several materials such as silicon for the gums and the membranes, resin for the teeth, plastic for the supports… Such simulator aims to prepare an ergonomic environment close to the real clinical environment permitting the adoption of a good working position, adaptation to indirect vision, correct handling of rotating instruments… [14]

Figure 3: Typodent designed for teeth extraction training



Figures 4, 5: Typodent designed for surgery training

2.4. Robot patient

These very high-fidelity simulators were first introduced in 2011 by the collaboration between the university of Showa and Tmusk Co Ltd in Japan. Reproducing the look of a well-dressed human being, these robots are operated remotely by an instructor and are capable to simulate several movements such as talking and interacting with the practitioner, blinking, breathing, swallowing saliva, responding to painful stimuli or even simulating a nauseous reflex… [4,14,15,16]

2.5. Digital systems

2.5.1. Computerized simulation

The use of computerized simulation in dental medicine dates back to the 1980s. Such simulators which include serious games consist in manipulating interactive computer applications that include text, images, video, sound, animation… They focus on the development of diagnosis and decision-making skills through programs that are based on the principles of problem-based learning [17,18,19,20,21,22]. V-DIT is one of these serious games that are specifically designed to train learners to make decisions about dental implants in their spare time. It was introduced in 2009 by one of the leading game-based technology developers Breakaway in association with the Medical College of Georgia. [4]

2.5.2. Virtual simulation

Parallelly with the development of robotics during the second half of the 20th century, one of the major dental innovations is the development of virtual reality dental training simulators with haptic, visual and sound feedback in order to develop and maintain the sensorimotor necessary skills for the future practitioners [23,24,25,26]. These simulators have been developed by many universities either independently or through collaborations [14]. The main virtual simulators that appeared in the literature are cited below:

The Virtual Reality Dental Training System (VRDTS)

Developed in 1990 by the collaboration between the Harvard School of Dental Medicine and Novint Technologies [14,27], it aims to help learn tooth preparation and restoration. It consists of a workstation, a haptic device and dental simulation software that simulates a set of dental instruments (Low-speed drill, an explorer, two carvers, a carrier and a packer), the amalgam material and a single molar [24]. The tooth and the cavities are displayed as virtual images on the screen. The learner must hold the haptic device in the air and move it to control the virtual dental instrument and thus prepare and restore the simulated tooth. The major disadvantage of this simulator is that it does not support the correct positioning of hands and fingers because the learner holds the haptic device in the air [24,28].

The Iowa Dental Surgical Simulator (IDSS)

Developed in 2001 by the College of Dentistry of the University of Iowa in collaboration with the Graphical Representation of Knowledge (GROK) Lab, it aims to develop and evaluate the tactile and surgical necessary skills for clinical detection of enamel and dentine cavities [27]. It consists of three elements : a computer, a monitor and a force feedback device with corresponding software. Participants interact with the computer by manipulating an explorer attached to the force feedback device which permits them to receive different haptic responses. The main disadvantage of this simulator is that it focuses more on the development of tactile skills than on the development of psychomotor skills [24, 28, 29,30].

The PerioSim

Developed in 2006 by the University of Illinois in Chicago (UIC) through the cooperation between dentistry and engineering colleges, it is specially designed for the learning and evaluation of the periodontal pockets, tartar detection, tartar removal and the detection of White Spots. It consists of a high-quality computer unit, a haptic device and a monitor with stereoscopic glasses. A 3D human mouth is instantly simulated on the screen with the possibility to adjust its position, angle of view and level of transparency. PerioSim is actually part of the curriculum of the UIC's periodontic department. The disadvantage of this simulator is that the tactile sensations of the gingival tissues are not realistic. [4,24,27,31,32,33]

The Virtual Dental Patient (VDP)

Developed, in 2006, by the University of Thessaloniki (Greece), it aims to familiarize users with the anatomy of teeth and the different instruments manipulation [27]. It allows the user to manipulate a three-dimensional head and mouth model constructed using anatomical data, adapt the model to the characteristics of a real patient via either facial

photographs or three-dimensional data, and animate it using a MPEG-compatible facial animation player. The model is composed of mouth tissues, teeth and head-neck tissues. This simulator uses a haptic device to perform virtual tooth drilling. [24,34].

The VOXEL-MAN simulator

Developed, in 2007, by the VOXEL-MAN group at the University Medical Center in Hamburg Eppendorf, it allows the learner to virtually manipulate a mirror for visualizing the different faces of the simulated tooth as well as different shapes of burs which are controlled by a foot pedal. It provides instant haptic feedback. Differences in sensations between enamel, dentin, pulp and carious tissues are accurately reproduced. It allows also training for apicectomy surgery. [4,27,35,36].

The HapTEL (Haptic Technology Enhanced Learning) simulator

The first prototype of the HapTEL simulator was developed in 2008 by the collaboration between the King's College London Dental Institute and Reading University (UK). It allows users to learn and practice different procedures like caries detection and making the corresponding restorations [27]. It consists of two screens that allow the user to look down on a simulated 3D mouth, a specially designed software and a pedal. It permits the learner to replay several times the procedure that he has performed with increasing degrees of simulation complexity [24].

The Kobra simulator

Developed by the Forsslund company in 2008, its main purpose was to learn the surgical extraction of the wisdom tooth [27]. Currently, this simulator uses haptic technology and 3D stereoscopic visualization combined with dynamic software permitting the adding of new cases of patients [37].

The Simodont simulator

Developed, in 2009, by the cooperation between MOOG Nieuw-Vennep in the Netherlands and the Academic Centre for Dentistry in Amsterdam, it gives the learner the opportunity to practice several dental procedures such as the manual dexterity enhancement exercises with instant feedback, diagnosis and treatment planning, cavities preparation, crown and bridge preparation… It consists of a central processing unit, a touch screen giving access to the various options, a stereoscopic projection screen, a mouse for manipulating the virtual model, a hand piece with haptic force feedback, a hand rest, a pedal, a virtual mirror and stereoscopic projection glasses [4,24,27].

The Virdent System

Developed, in 2011, by the Faculty of Dental Medicine at the University of Ovidius in Constanta (Romania), it is dedicated to the training of the fixed dental prostheses (crown and bridges) preparation [27,38]. It consists of a drill, virtual teeth and virtual patients, a haptic device and a pedal. It allows the learner to reproduce a preparing teeth procedure which is demonstrated by an intelligent tutor and to correct their work in case of error [24,39].

The iDental simulator

Developed, in 2011, by Wang and coll at Beihang University in China, it was designed especially for learning periodontal procedures and conservative odontology procedures by ameliorating the bimanual dexterity of the learner [27,40].

The Virteasy Dental simulator

Introduced, in 2011, by the DIDHAPTIC company (France), it was initially designed to train implantology and then its field of training was expanded to cover the other fields of dentistry (conservative odontology, endodontics, prosthodontics…) [27,41].

2.6. Mixed systems

They consist of the addition of a real-time space tracking device and a computer to a standard training unit (phantom head with typodont). This type of computer-assisted simulation is very useful for an objective and fair assessment between students while allowing them to visualize on the computer screen their errors and the corrections to be made in their preparations. The main computer-assisted simulators that appeared in the literature are cited below:

2.6.1. The DentSim simulator

It was developed by the DenX Ltd in 1997. It can be installed on an existing phantom head simulation unit by the addition of a computer, a camera, a special dental hand device and a tracking device [4,28]. It permits the students to practice clinical procedures on the simulated patient (phantom patient) with visual monitoring of their work on the computer, real-time feedback and evaluation of their performance [24]. The student's preparation is recorded and compared to an ideal preparation that is predesigned and selected from the software database. This allows students to compare their preparation to the ideal preparation and make the appropriate corrections. Actually, it is used in many dental schools around the world and is the subject of several research [24,42,43].

2.6.2. The CDS-100 simulator (EPED system)

It is made by EPED and is marketed as CDS-100. It is based on the same operating approach as DentSim [4].

2.6.3. The IGI (Image Guided Implantology) simulator

It is developed by DenX Ltd and is specifically designed for teaching implantology including diagnosis, treatment planning and implant placement. It uses the same technology as the DentSim unit in addition to the possibility of obtaining a composite virtual reality of a real patient by entering the computed tomography or the magnetic resonance imaging of the patient into the simulation unit. The diagnosis, treatment planning and virtual testing surgery of implant placement can be performed on the simulated patient. This simulator presents an exciting specificity which consists in the possibility of the inclusion of a recording device that can be used during the real surgery allowing so the real patient and the virtual patient image to be coordinated. In this way, the surgeon can take advantage of the computerized images to guide himself and the computer will warm him if he deviates from the treatment plan. If the computer recognizes that the surgeon makes a serious deviation from the treatment plan during surgery, it will stop the hand device and the surgeon should make adequate corrections to be able to continue [28].

2.6.4. Advantages of dental training simulation

Simulation is one of the active pedagogical methods which can be used in healthcare training. It aims to immerse learners in a simulated clinical situation with technical problems to overcome [3]. It has several advantages such as learning to manipulate the various dental instruments (mirror, probes, high and low-speed rotating instruments, familiarization with ergonomic positioning and improving manual dexterity [5]. Similarly, its importance in training medical emergency management in dental care has been recognized by many studies such as those conducted by Newby (2010) [44], Tan (2011) [6] and Roy and (2017) [7]. Concerning computer-based simulators like the DentSim simulator, several researches have been conducted to check their validity and their contributions to student training [45]. Indeed, Buchanan [28] found that students who trained with a computer-assisted simulator learn procedures twice faster than students who trained with conventional methods. Also, Jasinevicius and coll (2004) found that students who received computer-assisted simulator training needed significantly less training time to achieve acceptable levels of performance than students who received traditional training. Moreover, the importance of the use of haptic force feedback in improving students' performance during a basic dentistry exercise has been demonstrated by numerous studies such as the one conducted by Suebnukarn and coll (2010) [46]. These virtual reality simulation devices permit a safe practice of the dental care without harmful consequences for the patient. In addition, they allow students to visualize their performance with objective evaluations and repeat dental care procedures as many times as necessary until the acquisition of the required fundamental gestural automatization for their clinical practice. In 2007, the study that was conducted by Von Sternberg and coll [36] for the exploration of the Voxelman simulator, showed the interest of such simulator in the learning and the mastering of apicectomy. In 2010, Pohlenz and coll [35] also undertook a study of the Voxelman simulator. They found that training on such simulator improved the learning scores while limiting the risk of nerve and vascular lesions. Besides, in a student evaluation of the use of virtual reality simulation within the study conducted by Rees and coll (2007) [47], three main benefits of such tool are derived:

- The ease and the possibility of using a large number of preparations in a single training session.
- The work autonomy with an individualized pace and automatic objective evaluation by the simulator.
- The possibility of manipulating the tooth during treatment from different angles of view which is not possible with physical systems. [3,47]

2.6.5. Limits of dental training simulation

The apparent success of these new simulation technologies is sometimes more suggested than strictly evaluated since some aspects especially psychological ones are not yet quantifiable [3]. Besides, some of the mentioned digital

simulators are still in development and in some cases, they are still in the experimental phase. Similarly, due to the lack of standards, these simulators differ widely in the design and the algorithms as well as in the methods and the evaluation [27]. Finally, the initial development cost of such simulators is too high although it tends to decrease with the use in addition to the cost of their maintenance and their repair which require significant skills and budgets [28].

3. Conclusion

As in all other areas of health care, simulation seems to be one of the essential teaching methods for the training of dentists. It has been used since almost the creation of the first dental college in the 19th century. It has progressed from the use of natural teeth, to the simulation of patients by the phantom head mannequins, to computerized simulation followed by the use of virtual reality reinforced by haptics until most recently robotization. However, despite all the progress that it is witnessing and to be more effective, simulation training must respect a number of fundamental rules such as its integration into the overall curriculum training and the best conduct of the phase of debriefing.

Compliance with ethical standards

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Disclosure of conflict of interest

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