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Augmented reality in clinical dental training and education

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NARRATIVE REVIEW

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Abstract

Dentistry is a profession that requires coordinated motor skills in addition to acquired knowledge for ideal execution of any treatment plan for patients. Learning experiences have been modified over a period of time for students as well as for the healthcare providers. Conventional pre-clinical training employed the use of cadavers, but financial, ethical and supervisory constraints have become a major shortcoming. With the adaptation of technology in dentistry, pre-clinical training has now employed simulation. It provides the opportunity for students to develop psychomotor skills for procedures by practising pre-clinical, standardised learning competencies before they engage in patient-management. Simulation involves computer-aided learning, augmented reality and virtual reality, which are largely taking over pre-clinical teaching. Augmented reality is commonly being employed in maxillofacial, restorative, tooth morphology learning and mastering technique for administering local anaesthesia in dentistry. Virtual reality is being employed particularly in pre-treatment implant planning and dental education for students. Use of haptic technology, like robotics, is also gaining popularity, and facilitates a two-way communication between the user and the environment to better simulate the clinical setting for learning purposes.

Keywords: Augmented reality, Virtual reality, Dental education.

Introduction

Dentistry is a profession that requires coordinated motor skills in addition to acquired knowledge for ideal execution of treatment plan for the patient.[1] Learning experiences in this field have been modified over a period of time for students as well as for the healthcare providers. While cadaveric study had been the gold standard for teaching anatomy to the students, financial, ethical and supervisory constraints have been a major shortcoming. The knowledge learned from books and lectures is reinforced by three-dimensional (3D) knowledge from cadaveric studies. Cadaver-based procedures enhanced students' confidence to operate on their first patient and also contributed to reduction in the incidence of complications.[2] However, these learning goals can now be achieved by simulation, which is defined as a situation in which a particular set of conditions is created artificially in order to study or experience something that could exist in reality.[3]

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Development of dental simulation

Pre-clinical dental education has incorporated simulation for quite some time. It provides the opportunity for students to develop psychomotor skills for procedures by practising pre-defined, standardised learning competencies before they engage in patient-management.[4] Conventionally, extracted or synthetic teeth in phantom heads were used to facilitate the learning of techniques required in clinical practice. New experiences in learning, enable students to explore the human body without the limitations of cadaveric teaching. The next simulation generation is represented by the patient-simulating robot.[5] This robot is equipped with autonomous moving parts, a clothed body and a wig to simulate a patient. Furthermore, computer-aided learning (CAL), which provides digitalised computer-based instructions in health profession, is becoming an increasingly popular media for information transfer to patients, students and practitioners alike.[6-8] With continual development of information technology (IT), the use of advanced learning methods, including Virtual Reality (VR) and Augmented Reality (AR), have taken over conventional means of learning owing to their user-

Table-1: Comparison between AR and VR.

Augmented Reality (AR)	Virtual Reality (VR)
◆ Real surroundings (adds to the existing surrounding)	◆ Swaps the surroundings (create new surroundings)
◆ More freedom for the user	◆ More immersive
◆ No head mounted display required	◆ Head mounted display required
◆ Technology is much more developed	◆ Relatively new technology
◆ e.g. to directly observe a human body and to see virtual objects on it, or through it as the anatomy of the body was superimposed.	◆ e.g. a virtual reality system would be a head worn helmet which simulates navigation inside human body and the user to explore it on the basis of a virtual three-dimensional reconstruction.

integration advantage (Table-1).

VR and haptics

VR has been used over the course of time to practice procedure-related skills in pre-clinical dental setup and to facilitate programmes that would produce competent clinicians. This is brought about by pre-programmed integrated scenarios into operative environment and haptic feedback would refine tactile skills.[4] Computerised VR (CVR) simulators can be divided into two types: mannequin-based and haptic-based. Mannequin-based simulators enable the user to practice dental procedures with real dental instruments, while haptic simulators employ devices for feedback in virtual models and are used for operator training.[9]

Haptic technology is not new and is being used widely in telecommunication, aviation and medicine. The term itself refers to robotics, and facilitates a two-way communication between the user and the environment to better simulate the clinical setting.[10] Simulation in dentistry allows the operator to perform procedures on soft and hard tissues with tactile feedback by the sense of touch, and responds accordingly by applying vibration, force and motion to the user.[10] A haptic learning system for self-learning in local anaesthesia delivery was developed on anatomic models.[11] Simodont dental simulator enables a virtual environment in order to practice different dental operatory skills in virtual oral and dental environment.[12] This system enhances the simulation experience and makes it more realistic by producing convincing audio-visual effects during the user performance.[12]

Evolution of AR

AR has evolved in order to provide interaction ability with realistic experiences for the user. Compared to VR, which creates an artificial world that a person can explore interactively, AR software utilises the pre-existing environment and enhances the experience by adding virtual elements to it.[13] Widespread application of AR can be found around us in the field of arts, gaming, architecture, interior design, auto industry, archaeology and other areas.[14] Several procedures have administered AR in biomedical sciences and continual efforts are being made for their advancement which has led to mobile devices with AR.[6]

Integrating realistic experiences in pre-existing setup is required to achieve optimum skills. Various researchers are in agreement that significant educational and motivational potential in teaching and learning through AR to promote group, individual and interactive learning experiences.[15] There are several tested techniques that present well-accepted standard architecture for such systems.[16] The field has matured to such an extent that intelligent tutoring is accepted as a key technology in learning institutes.

AR versus VR

Though they sound similar, there are critical differences between VR and AR (Table-2).

AR and local anaesthesia

Table-2: Advantages and disadvantages of augmented reality (AR) and virtual reality (VR).

Advantages	Disadvantages
◆ Reinforcement of learned dental concepts	◆ Continually developing software of which most are in experiment phase
◆ Orientation to the use of dental instruments	◆ Limitation of the available system to carry out procedures
◆ Careful ergonomic positioning	◆ Limitation of the available instruments/tools in system
◆ Development of coordinated motor skills	◆ Cost in installing initial setup of simulation
◆ Standardized assessment in evaluation	◆ Maintenance of equipment
◆ Self-evaluation without supervision	
◆ Positive student perception for freshman	
◆ Faster acquisition of skills	
◆ Availability over many hours for practice	

Local anaesthesia administration is an essential skill in dentistry. A clinician in training should be able to germinate fine, coordinated motor skills for professional clinical practice. One of the most common and highly important procedures in dentistry is a widespread use of mandibular anaesthesia in various specialties, including oral surgery, endodontics, periodontology and prosthetics.[8]

Initial execution of the procedure can induce anxiety and stress among dental students. Procedure-related anxiety in students and patients can be reduced by theoretical knowledge of the clinician and step-by-step practical instructions in the administration of anaesthesia.[17] The position of mandibular foramen and lingula are anatomical landmarks of importance when delivering regional mandibular anaesthesia. Chances of error due to positioning and failure in identification of these landmarks is reduced by the use of AR which helps in localisation and identification of anatomic reference points in the oral cavity.[8] Won and Kang et al. invented a relatively simple AR method to administer mandibular anaesthesia in training by virtue of Cone-Beam Computed Tomography (CBCT) and advanced dental software. The provided information by AR technique, related to the bony structures in oral cavity, can be referred for the administration of anaesthetic injections in order to accurately locate the position of mandibular foramen with greater ease. AR provides related information for bony structures in the oral cavity that can be referred to during anaesthetic injections in order to easily and accurately locate the position of the mandibular foramen.[18]

A mobile dental simulator (v1.13, Campinas, Brazil) was used in a study by Mlandenovic et al. for anaesthesia training of the inferior alveolar nerve (IAN). Conventional training methods for mandibular anaesthesia were compared with AR mobile simulator, and it was concluded that students receiving additional training with AR reported significantly shorter procedure time for anaesthesia. Students were acquainted better with anatomical landmarks for the performance of IAN block, and, thus, had a better control over syringe during the procedure[6] (Figure-1a-b).

AR in restorative dentistry

The field of operative dentistry is one of the most demanding areas in clinical education. Increased knowledge, combined with clinical problem-solving skills, can result in a competent clinician.[4] Simulation in pre-clinical dental education utilises teeth embedded into synthetic jaws to allow the students to acquire basic skills in restorative dentistry. This assembly consists of a laboratory mannequin head affixed to benches that would allow adjustment of position in order for students to work as they would in a clinical setting.[8] Cavity preparation in pre-clinical setup using AR was studied by Llena et al.[19] The participants that used AR for education showed significant improvement in skills related to Class I and Class II cavity preparation.[19] It should be emphasised that cavity preparation and the understanding of different parts of cavities is strongly conditioned by spatial vision[19] (Figure-1c).

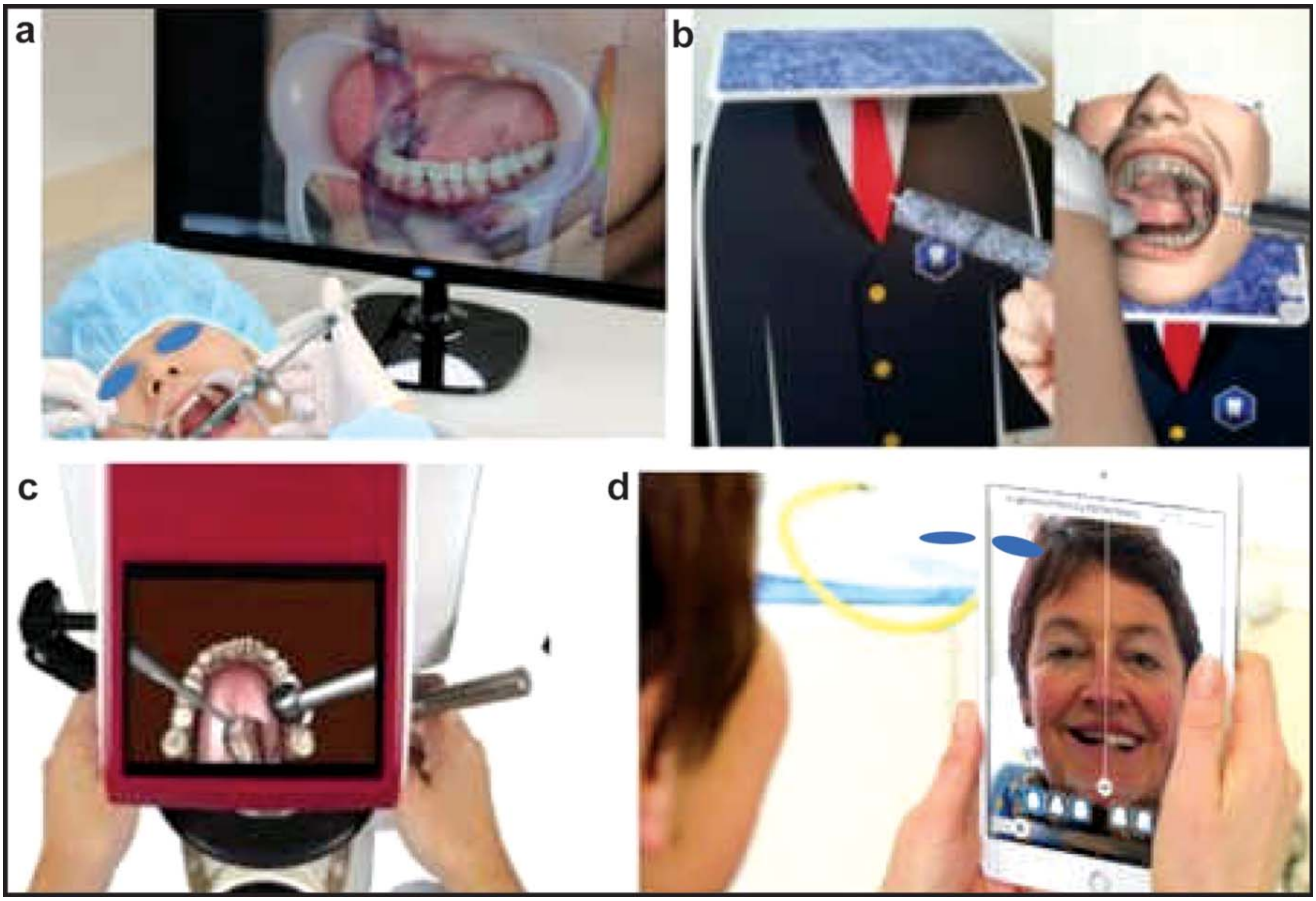

Figure-1: a) Local anaesthesia in augmented reality (AR); b) student practising for local anaesthesia in AR; c) Simodont virtual cavity preparation; d) Smile makeover in IvoSmile.

AR in aesthetic dentistry

Dentistry owes a well-acclaimed role in patients' cosmetic appearance. AR has found its way in the field of cosmetic dentistry. AR integration enables direct aesthetic makeovers on the patients by virtue of mobile devices. It enables the mobile device to turn into a virtual mirror so the patients can visualise the final outcome and decide easily if they can go through it with a motivated mindset (Figure-1d).

The plan to be executed for change in aesthetics of patients can be viewed in the form of photo or live video mode. Patients can visualise themselves in speaking after the proposed aesthetic makeover is in place. The user is able to understand the final outcome in a better way, and they can focus their attention on the decision of proposed plan regarding shape, size and appearance. IvoSmile (Ivoclar Vivadent) software includes a "bleaching option" which could be utilised to advise patients on the ideal degree of whiteness.[20] Since the procedure has its limitations, smile design with the digital cast of the patient, and the addition of other face and tooth recognition markers was proposed.[21,22] However, more investigation of this innovative device is required.

AR in maxillofacial surgery

High accuracy, easy manipulation and improvement in surgical outcomes have paved the way for AR in the

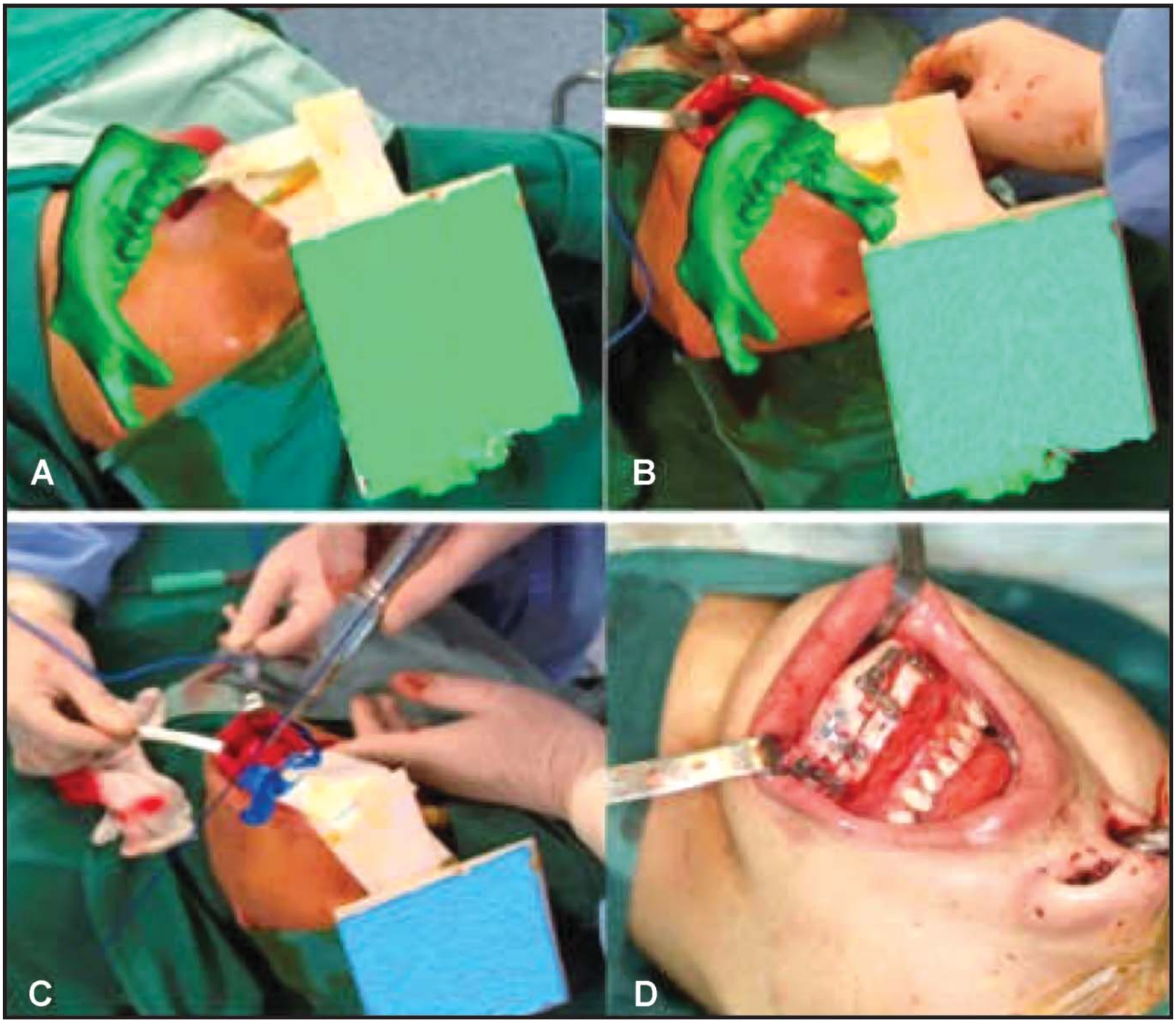

Figure-2: a-d) Augmented reality (AR) being applied during maxillofacial surgery.[24]

maxillofacial arena. Therefore, AR has significant potential with regard to clinical application concerning head and neck and orthognathic surgeries.[8,23]

AR ensures that the combination of VR and real environment results in low-risk and accurate surgery.[24] AR provides navigation by direct projection of pre-operative images onto the surgical field and the user continues to operate in real world environment.[25]

In a novel study by Zhu et al. registration and tracking was carried out using a splint for reference fixed to real prototypes model, and pre-surgical 3D casts. During surgery, minor jaw movements due to positional changes occur, which were accommodated by navigation due to availability of the reference splint. This study proved position error by this navigation to be 0.96±0.51mm[24] (Figure-2).

VR in dental implantology

Over the course of last three decades, it has become a common practice to rehabilitate edentulous spaces with osseo-integrated implant-supported prosthesis. This precise, technique-sensitive placement of prosthetic driven implants must meet the demands of occlusion in function, phonetics, aesthetics and longevity.[26]

True implant orientation and position could be assessed by 3D visualisation in AR. This can be the potential future for dental implant surgery owing to simpler procedure and operating time in dynamic navigation outcome.[8] Treatment planning that takes place in the virtual world allows the operator to place virtual implant by interacting with individual patient's anatomy with a degree of freedom prior to performance of the procedure[27] (Figure-3a) or during the procedure.[28] This is simulated in real time and thus feedback for adjustment can be immediately given for accurate placement. Moreover, implant sizes can be chosen with regard to patient's bone quality and quantity that can be visualised in the VR environment and with in-situ image guidance.[28]

Figure-3: a) The view of the surgeon while performing a surgery with HoloLens glasses. b-c) Application of augmented reality (AR) in learning dental morphology (Image Target and the augmented scene); d) Performing endodontic access cavities (green cylinders) controlled in all planes and depth with fixed black-and-while tag (red arrow) attached to high-speed hand-piece (green arrow).

AR in dental morphology

Dental morphology deals with study related to tooth anatomy to know specific shape, size, position, function, structure, occlusion and development of teeth.[29] It is essential in all dental specialties to know dental morphology and variants.[30] The use of VR integrating all relevant 3D information gives the students a spatial impression of tooth morphologies in order to better understand and motivate them in their learning[30,31] (Figure-3b). Therefore, AR can be used as a valuable tool in clinical as well as laboratory setting for the study of teeth in occlusion.[29]

Juan et al. first developed AR system for learning dental morphology (Figure-3c) and conducted video sessions to measure learning outcomes. The study showed that AR was effective in knowledge transmission and the mobile device was of great help in reinforcing acquired knowledge. It also concluded that knowledge can be acquired by this method irrespective of gender age or specialisation.[29]

VR in dental teaching and learning

Students' knowledge has improved by VR and it has proved to be effective in patient evaluation and teaching clinical reasoning.[32] This highlights the importance of VR in order to standardise clinical education to facilitate dental learning and training. Students were encouraged to self-learn by these methods which reduced faculty time significantly. Objective structured clinical examination (OSCE) can easily involve the use of simulators.[33] Learning environment for training in maxillofacial emergencies can be virtually created to improve confidence and knowledge of junior trainees.[34] There are limited prospective randomised studies to assess the impact of VR with standard methods of delivering education or carrying out oral surgical procedures.[34] From the ethical standpoint, the introduction of VR in clinical teaching might reduce the number of natural teeth used for restorative training.[8]

Future prospects in AR

AR facilitates the transition of a student to being a practicing clinician. The multitude of systems that are currently available enable the clinician to perform complicated procedures in less time by virtue of AR. Clinical procedures as guided surgeries, including implant placement, micro-endodontics and orthograde complex endodontics, require precision that is facilitated by the mechanics involved in AR. One such example is dynamic navigation in access preparation.[35] Further studies with developing software will be helpful in educating dental students even in unprecedented times, like these of the Coronavirus disease 2019 (COVID-19) pandemic, in order to continue their curriculum without any hiccups of physical presence.

Conclusion

The benefits of VR with the support of AR is clearly evident. Enhancing opportunity in education, AR facilitates a variety of learning procedures and activities that could be performed without supervision. This combination of VR and environment exposes students to interactive learning as they would in a clinical setting. This improves knowledge and skill among dental students and reduces their anxiety while executing a treatment plan. Moreover, this also provides access to quality interaction, educational resources and lowered cost of overall training. A number of programmes are continually developing in order to ease the transition of a preclinical dental student into a practising clinician worldwide by the aid of technological advances in simulation and haptic feedbacks.

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