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Augmented Reality Technology-based Dental Radiography Simulator for Preclinical Training and Education on Dental Anatomy

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Abstract

It is important that students are provided opportunities to practice their skills in acquiring radiographic images. However, these opportunities are currently limited because of the risk of radiation exposure. To overcome this limitation, a new augmented reality-based radiography simulator was developed that enables students to practice radiographic techniques as part of self-directed learning without time and space constraints. Subsequently, cross-sectional images of a manikin phantom head obtained via computed tomography were reconstructed into a three-dimensional object. An image marker that could be recognized by a mobile device and could allow users to practice dental radiography techniques was devised. The three-dimensional object was augmented to the mobile device; consequently, among 106 stored dental radiographs on the device, a radiograph corresponding to specific imaging conditions was opened when users performed radiographic procedures. This technology could improve dental students' understanding of dental anatomy and contribute to improving their competency in acquiring dental radiographs

Index Terms: Augmented reality, Dental anatomy, Dental radiography simulator, Preclinical training

I. INTRODUCTION

Augmented reality (AR) is a type of virtual reality technology in which real-world and virtual images are overlaid on the screen of a device, allowing for additional information to be displayed in real time [1]. AR technology has a wide range of applications in the fields of clinical medicine and dentistry, particularly in the development of learning tools for studying human anatomy [2] and practice tools for surgery [3] and for the superpositioning of radiographs [4]. However, due to the lack of an error checking system, most AR applications are used for training purposes only. Many researchers have demonstrated the advantages of using AR technology to develop training tools [5-7] that can be used for simulation-based training of doctors in their preclinical years [8, 9].

It is important for clinicians to possess well-developed clinical skills in specific settings, particularly in a hospital setting, to ensure patient comfort and safety [10]. Students in medical, dental, and health science schools who are training to be clinicians in the future must complete practice courses while they are in the preclinical stage of their course and must develop clinical skills via the practical application of basic knowledge and repeated practice sessions. However, to become proficient in their clinical skills, students should practice using human bodies or specialized tools and materials that are only available in certain settings, such as in a clinical laboratory at a university or hospital. Therefore,

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there are many time and space constraints associated with clinical learning. In dental medicine, clinical experience in obtaining dental radiographs for diagnostic purposes is acquired via the use of oral radiographic equipment [8]. In Korea, both dentists and hygienists require skills in performing oral radiographic procedures. Therefore, hygienists must also understand human oral anatomy, for which e-learning training tools are occasionally effective [11]. Dental radiography is targeted to the maxillary and mandibular teeth and surrounding bones; therefore, it is important for future dental health professionals to understand the three-dimensional anatomic structure of the mouth and to become proficient in deriving two-dimensional information from radiographs [12].

In general, dental radiographs are acquired using the bisecting and bite-wing techniques in which the positioning (i.e., at horizontal or vertical angles) of the dental radiographic head tube is an important factor. During their preclinical years, to acquire skills in capturing radiographic images, students tend to practice on each other; however, cumulative radiation exposure can lead to serious consequences on the human body [13]. In Korea, the use of a manikin phantom head (MPH) is recommended by the guidelines outlined by the Radiation Safety Management System (which maintains radiation exposure records for routine users and improves the efficiency of physical examinations) and by the Revision of Nuclear Safety Act (radiation safety management regulations that were enacted in 2017). However, there are some limitations associated with the use of an MPH as a learning tool: the acquisition of clinically relevant radiographs is an expensive process; an MPH can only be used in a clinical laboratory; and only a small number of images can be obtained.

Therefore, the aims of the present study were to develop an AR technology-based simulator that overcomes limitations, such as radiation exposure and the need for an expensive MPH, and that provides students with ongoing opportunities in acquiring skills associated with dental radiography during their preclinical years and in improving their understanding of oral anatomy with the help of dental radiography simulator-based augmented reality (DRS-AR) technology.

II. SYSTEM MODEL AND METHODS

The AR system that we devised for students to practice the acquisition of intraoral radiographs is configured as follows: when the DRS-AR application is installed on a mobile device (MD), the camera in the MD recognizes the image marker (IM), and the MPH is loaded onto the device as a three-dimensional object (3DO). For radiographic simulation, the system is configured to execute the graphical user interface of the MD when the student touches the screen in a stepwise manner, which allows the student to practice the bisecting and bite-wing techniques and provides them with an opportunity to learn the anatomic structure of both the skull and maxillary and mandibular teeth via the MPH. The system was designed using an application program interface whereby users are alerted when radiographic errors occur owing to incorrect imaging positions during the simulation of radiographic procedures with DRS-AR, thereby enabling them to excel in performing radiographic techniques correctly and efficiently.

Images of the MPH (Angiographic CT head phantom, Kyoto Kagaku Co. Ltd, Kyoto, Japan) that was used to practice dental radiography procedures were acquired using computed tomography (CT). Subsequently, DICOM files containing 160 cross-sectional images of the MPH were reconstructed using a 3D reconstruction software application (3D Slicer 4.8, open source: https://www.slicer.org). After being exported in the stereolithography format, the images were then imported using the Blender software (blender 2.78, open source: https://www.blender.org). The 3DO image was then created by making some modifications to the images to enable the student to observe the morphology of the maxillary and mandibular teeth in more detail.

Regarding the IM, customized images were drawn using the Photoshop software and were registered using the image target function in Vuforia (open source: https://unity-landing.vuforia.com/#imagetarget, Qualcomm, San Diego, CA, USA), thereby resulting in the generation of the marker. When the DRS-AR application was opened, the IM was recognized by the MD camera, and the 3DO representing the MPH that was saved in the MD was displayed on the screen. The MDs used were either the Galaxy Note 4 or S8 (Samsung, Korea). The following were the specifications of the MD camera that was used as the image sensor: Sony IMX BSI COMS (aperture F/2.2) and Sony Exmor RS IMX260 BSI CMOS (aperture F/1.7).

The bisecting and bite-wing techniques were performed on the MPH, and images with the vertical and horizontal angles of each tooth were recorded using a dental radiographic device and the Unity software (2017.3, Unity Technologies, San Francisco, CA, USA). The positions of the teeth were also recorded on clinical intraoral radiographs to allow users to experience simulations of various clinical cases. The gyro sensor of the MD evaluated the positions of the head tube of the dental radiographic device that was used to record the horizontal and vertical angles. The DRS-AR technology can also display radiographs if the position values that are saved on the radiographs correspond to those recorded by the gyro sensor of the MD. The system is configured to display an alert in response to incorrect information on the screen of the smartphone so that a user can accurately guide the camera to achieve an appropriate angle. All procedures used in the present study, including radiographic imaging, the use of radiographs, and the development of the application, were performed with the approval of the institutional review board (IRB) of Namseoul University (NSUIRB-201804-002).

III. RESULTS

After the DRS-AR application was open on an MD and After the DRS-AR application was opened on an MD and the IM was recognized, users could select teeth for the simulation exercise on the interface presented in Figs. 1(a) and 2(a), and they were able to focus on the specific dental structures by tilting or moving the MD to view the 3DO representing the MPH (Fig. 1(b)).

The MD display screen was divided into two windows in a ratio of 1:3 (left to right; Fig. 2). The left side was configured to display a control panel through which users could control the settings of the application based on their needs while checking the condition of the skin, bones, and teeth before capturing images. The right side displays the part of the MPH model that is currently being focused on by the MD camera, and allows the user to review the captured images. The system was configured such that the position of the MD camera was the same as that of the head tube, which acts as a reference for capturing radiographic images. There are four icons in the panel on the left side of the display window, and the outer morphology of the MPH, including the skin of the head, can be examined if a user touches the icon representing a human bust presented at B in Fig. 2. This enables users to practice radiographic techniques as if they were capturing radiographs of a real human patient. If a user touches the skull icon shown at C in Fig. 2, the skin immediately disappears, allowing the user to identify the anatomic structures of the skull and crowns of the maxillary and mandibular teeth (F1 in Fig. 2). When a user touches the tooth icon shown in Fig. 2D, the anatomical structures of the crowns and roots of the maxillary and mandibular teeth can be observed while the skull is excluded from the view (F2 in Fig. 2). In the right window of the screen, a user can select the specific teeth whose image is desired, following which the application displays the correct horizontal angle (i.e., horizontal positioning of the MD) and vertical angle needed to perform the radiographic simulation exercise; it provides real-time information on the vertical angle of the MD (E in

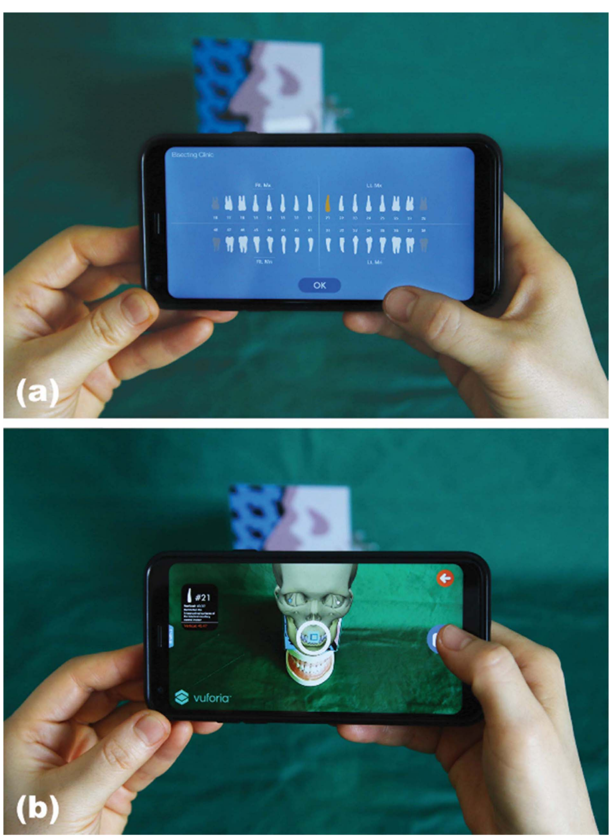

Fig. 1. Utilization of the dental radiography simulator-based augmented reality system installed on a mobile device (a, preparation of radiography by touching the target teeth to be imaged; b, simulation of radiography on the image marker).

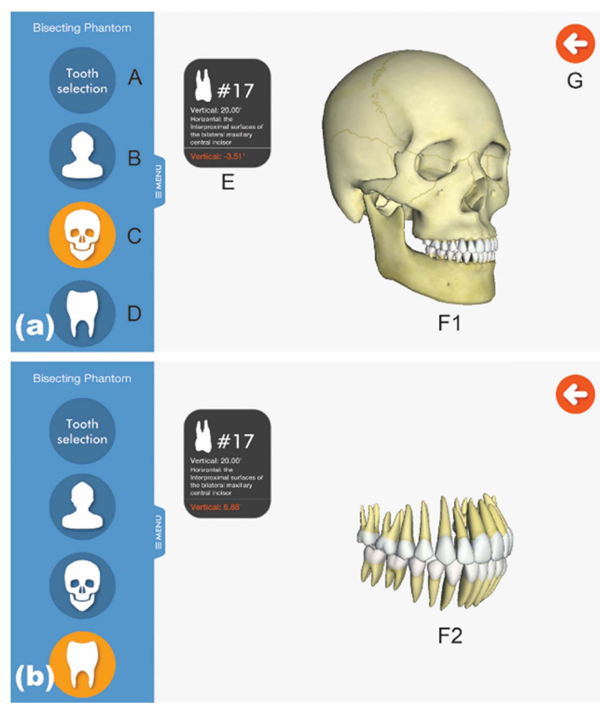

Fig. 2. Three-dimensional models of skull (a) and the teeth (b) on the display screen of the dental radiography simulator-based augmented reality system (A–G, executable icons by touching on the graphical user interface; A, the tooth selection icon for simulation of radiography; B, the icon to show or remove the skin by touching; C, the executable icon for identification of the anatomic structures of the skull and teeth by touching; D, the icon to show only the morphologic structure of the teeth; E, information about camera angle for teeth that appears in radiographic simulation when the ‘A’ icon is touched; F1, identification of skull anatomy that appears after touching the ‘C’ icon; F2, identification of teeth structure using a three-dimensional model of the maxillary and mandibular teeth when the ‘D’ icon was executed; G, for execution of the command in the previous step).

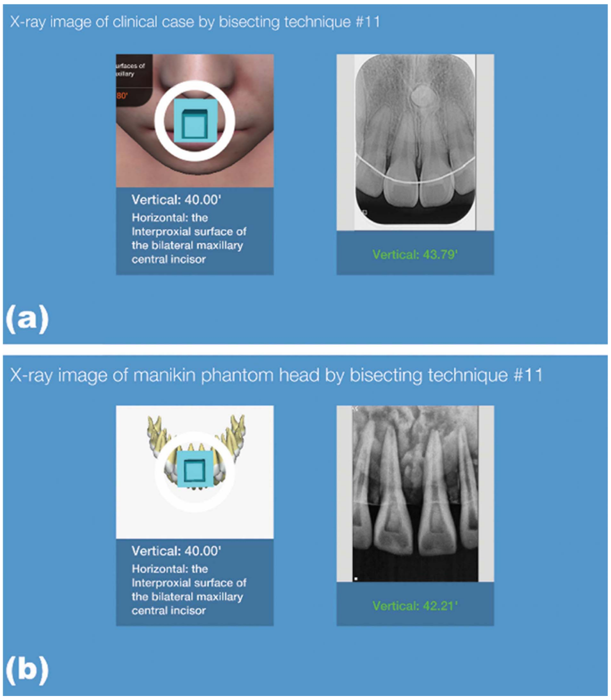

Fig. 3. Outcomes of radiographic simulation by the dental radiography simulator-based augmented reality system (a, display of radiographic image in a clinical setting; b, display of a radiographic image of the manikin phantom head; white circle, range of teeth to be imaged; light blue rectangle, a superior view of the three-dimensional arrow, in which the smaller inner rectangle and the larger rectangle represent the pillar and the head of the arrow, respectively. This shows the vertical and horizontal positions of the mobile device in real time).

Fig. 2).

The dental area to be recorded in the radiographic image is indicated by a white circle. If the button to capture an image is touched on the MD when the cross-section of the tail of the 3D arrow is placed in the center of the white circle, a radiographic image of a clinical case (Fig. 3(a)) or of the MPH (Fig. 3(b)) is displayed on the screen. With this application, a user can also compare the appropriate angle to be used to capture an image at the actual angle that was used by the user in their image capturing attempt while simultaneously being able to check the vertical angle that is displayed in a box at the bottom of the screen in real time, thereby enabling repeated practice attempts (Fig. 3).

IV. DISCUSSION AND CONCLUSIONS

AR technology has been proven to be very useful in the medical field, and there have been many studies on the use of this technology in the areas of surgery, diagnosis, and training [3, 14, 15]. However, there have been few studies on the use of AR technology in the dental field. The demand for AR technology in dental medicine has steadily increased, particularly in terms of the development of training tools that can be used to enhance a student's clinical skills during the preclinical years [16]. Many researchers have developed AR-based software applications involving the use of 3DOs and have predicted that these applications would have positive effects on student training [7, 11, 17-19].

In dental medicine, radiography is a useful imaging modality for the diagnosis of oral conditions in patients. Cross-sections of the mouth can be visualized in many ways depending on the imaging methods employed; therefore, it is important for dental health professionals to be familiar with the various radiographic methods available [12]. In general, dental radiographs are acquired using the bisecting and bite-wing techniques; the vertical angle involved in imaging techniques depends on the positioning of the dental radiographic equipment (i.e., the head tube); therefore, using an appropriate angle is important for obtaining accurate radiographs. Generally, students practice radiographic techniques on each during their preclinical years. However, the opportunities to practice on other human bodies are limited owing to the risk of cumulative radiation exposure [13, 20]. Moreover, although they can acquire clinical working knowledge by using an MPH, this learning tool is very expensive and its repeated use for training purposes is restricted because it can only be used in a clinical laboratory and only a small number of images can be obtained.

Using AR technology, we developed a DRS-AR that enables repeated practice sessions without a student needing to be in a clinical laboratory. Students in their preclinical years can practice the acquisition of dental radiographs using an MD without any hindrances or limitations (Figs. 1 and 3). Specifically, they can independently learn the morphology of the bones and teeth by studying a CT image-based 3DO representing an MPH (Fig. 2). Additionally, the DRS-AR can be used to obtain dental radiographs of patients with various dental abnormalities, such as caries, dentures, and malocclusion, which can enhance the training experience for users (Fig. 3(a)). The DRS-AR facilitates real-time acquisition of information regarding the camera angle, thereby providing students the opportunity to become proficient in radiographic techniques, specifically in positioning the head tube of dental radiographic equipment. At present, this application is only available for iOS users, but it should be available for Android users in the future. Future research should involve a pre- and post-evaluation of the skills of students who have worked on the application in both Android and iOS devices. Additionally, the incorporation of the DRS-AR technology into dental radiography procedures would improve the clinical competency of students.

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