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Original Article

Achieving new excellence in an augmented reality dental education system

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KEYWORDS
Augmented reality;
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AR simulator system

Abstract *Background/purpose:* SimEx-Plus (EPED. Inc) was already a mature augmented reality (AR) dental training simulator that allowed students to have a high quality dental education practice. Now the EPCAD software has been further developed into a comprehensive computer-aided design software. It helps relevant professionals learn how to create digital fixed prosthesis in a virtual environment. This study used the newly developed EPCAD software that was integrated within the SimEx-Plus to design dental restorations then digital output milling restorations. We hope that the SimEx-Plus AR dental training simulator can achieve the multi-purpose function in one machine.
Materials and methods: A right maxillary central incisor was prepared in the standard dental model. The restorations were designed by EPCAD software integrated with the SimEx-Plus and milled by a 4-axis dental milling machine (N4+, vhf camfacture AG). The internal gap of the restoration was evaluated.
Results: The internal gaps of the crowns set on the right maxillary central incisor were among 68.27–89.80 μm. The different setting for digital output did not influence the internal gap (*P* 0.05, One-Way ANOVA). However, the internal gap on the palatal side was larger than that on the labial, mesial, distal, and incisal surfaces ($P < 0.05$, One-Way ANOVA).
Conclusion: The new software EPCAD that was integrated within the SimEx-Plus AR dental training simulator could design restorations, and the designed restorations had good internal gap for clinical use. The professionals can learn tooth preparation and digital restoration fabrication by the SimEx-Plus AR dental training system.

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Introduction

Augmented reality (AR) and virtual reality (VR) simulator has been developed for many years. It has been carried out for training several medical fields, such as cardiology, laparoscopy, anesthesiology and dentistry etc.[1—8] Analysis of using AR in dentistry included implantology, maxillofacial surgery, oral surgery, dental cavity, dental education, orthodontics and endodontics.[9] Prosthodontics would be the second highest rate of the VR dental education filed.[10] Becoming an exceptional dentist requires not only academic education but also practical clinical training. However, there is a long-standing shortage of full-time teachers, often due to various factors such as salary disparities. Over the years, advancements in IT technology have led to the widespread development and use of computer-led digitalization. This trend has gradually transformed the dental industry, replacing traditional training methodologies for dentists with digitalized approaches. The innovation of digital technology has now become an indispensable element in dental clinical procedures and education.

In countries like the United States and Japan, dental students are required to undergo both written tests and clinical examinations in order to obtain a national dentist license. While dentists in other countries possess commendable skills, there is a lack of standardized clinical assessment for licensing examinations. This deficiency can be attributed to the absence of established examination methods. Merely relying on pencil-and-paper tests is insufficient for cultivating professional dentists. Instead, a computerized assessment system is necessary to simulate clinical realities and facilitate self-learning, thereby truly implementing a comprehensive medical education practice.[11]

In clinical skills education, AR/VR simulator has been proven to be an effective training model. The recent global impact of the COVID-19 pandemic has significantly affected many teaching and social activities, forcing them to be canceled or shifted to virtual and simulated formats. The healthcare, nursing, and long-term care sectors have also accelerated the adoption of AR technology. The dental simulator (SimEx, EPED Inc., Kaohsiung, Taiwan) is a highly interactive dental training system that integrates clinical simulation systems, evaluation systems and 3D virtual reality technology. It is specifically designed for the clinical education and training of dental students and professional technicians. Operations are recorded and can be reviewed for training, grading, and verification purposes. In 2021, Kaohsiung Medical University and Tohoku University in Japan conducted a clinical trial to assess user satisfaction with SimEx. The results showed that most of the test subjects agreed that SimEx can facilitate self-training and is a valuable learning aid for the department of dentistry. So SimEx offers simulation training and real-time feedback on score results.[12]

Through refinement and further development, SimEx-Plus (SimEx Plus, EPED Inc., Kaohsiung, Taiwan) was already a mature and digital dental AR simulator system. By providing training in restorations preparation, prosthesis design, and implant training, it systematically develops professional dental clinical skills. Now the EPCAD software (EPCAD, EPED Inc., Kaohsiung, Taiwan) was developed further that gave to learn digital crown bridge fabrication. By combining EPCAD software, this study used the newly developed EPCAD software that was integrated within the SimEx-Plus to design dental restorations, and used digital output to mill restorations. The purpose of this study was to investigate whether the accuracy of the restorations designed by EPCAD software that was integrated within the SimEx-Plus AR dental training simulator had high precision and was suitable for clinical use. We hope that the SimEx-Plus EPCAD system can provide comprehensive digital dental education and training.

Materials and methods

Preparation of the crowns

A right maxillary central incisor was prepared in the standard dental model (Model teeth, Kavo Dental GMBH, Warthausen, Germany) by a prosthodontist using SimEx-Plus EPCAD AR simulator (Fig. 1, SimEx-Plus, EPED Inc., Kaohsiung, Taiwan). The prepared model was scanned by desktop scanner with LED light (E1, 3 Shape Co. Copenhagen K, Denmark). Scanning time for full arch was 40 s. After scanning the model, the file was archived in initial standard tessellation language file (STL) format. Then the STL file was set into SimEx-Plus AR simulator.

The crowns were designed by EPCAD which was integrated in the SimEx-Plus AR dental simulator (Fig. 2). EPCAD software product was a computer-aided design software that provides dentists and related dental professionals with tools for evaluating dental prosthesis designs and treatment plans. EPCAD could provide 3D model positioning and editing, quick gingival line drawing and undercut display, parametric and database-driven rapid generation of prosthesis designs, fast and automatic deformation tools, and 3D model export in open STL format.

After importing the STL file, the dental model image and the software built-in image were merged into one through the occlusal surface. The dental technician drew the crown internal finishing line and designed the path of insertion and morphology of the crown. According to the output parameter, the crowns were divided into six groups. In Groups 1, 2 and 3, the crowns were designed by the built-in programming but had the different setting for cement when digital exporting by milling machine. The reserved cement spaces setting for Groups1, 2 and 3 were 0.08 mm,

Figure 1 The AR simulator: SimEx-Plus combines with EPCAD software.

0.06 mm, and 0.05 mm respectively. In Groups A, B, and C, the crowns were designed individually that each one had some different morphology adjustment. The cement space was automatically set by EPCAD software in Groups A, B, and C, so the crowns had the same built-in programming output parameter. All the designed crowns were milled with resin blocks (PMMA BLOCK, 15.4 × 19 × 39mm, Yamahachi Dental MFG. Co., Aichi, Japan) by a 4-axis dental milling machine (N4+, vhf camfacture AG, Ammerbuch, Germany).

Internal accuracy of the crowns measurement

The measurement of the internal gaps of the crowns were showed in Fig. 3. The mark point was glued on the abutment tooth, then scanned by the desktop scanner to establish the initial file. Then the tooth was precise scanned to establish the accurate morphology as the Image 1. The crowns were cemented on the abutment tooth by vinyl polyether silicone (Fit-Checker® Advanced, GC Dental Products Corporation, Aichi, Japan). Then removed the crown and left Fit-Checker® on the abutment tooth. The abutment tooth covered by Fit-Checker® was scanned by desktop as the Image 2. Image 1 and Image 2 were imported into software (Exocad, Exocad GmbH, Darmstadt, Germany) for image superimpose by mark point. The distance between the outline of the two images was defined the internal gap. Surveying sides were located at buccal, palatal, mesial, distal surfaces and incisal edge, and took 3 points measurements on each surface.

Statistical analysis

The results of the internal gaps made by different methods were compared using two-sample t-test, One-Way analysis of variance (ANOVA) and Tukey HSD as indicated in the

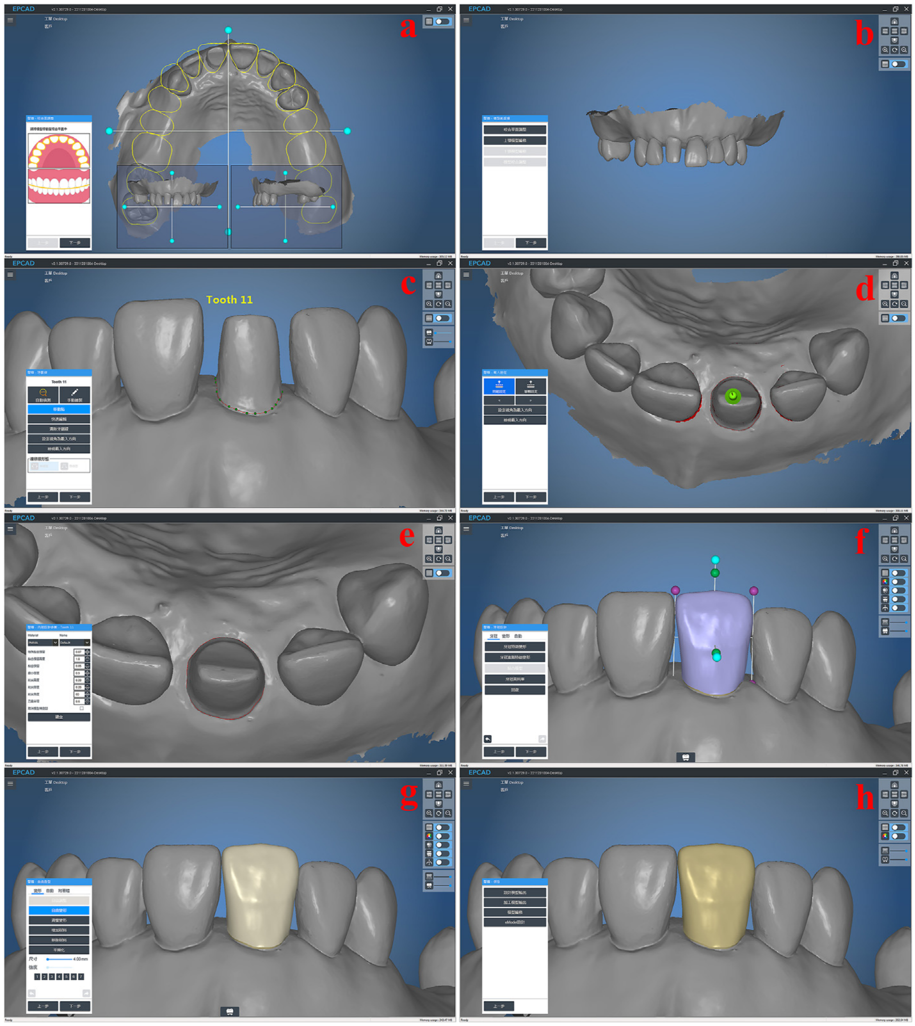

Figure 2 Crown of the maxillary central incisor (tooth 11) was designed using the EPCAD software. a. The image of the dental model from occlusal view. b. The image of the dental model from frontal view. c. Drew the marginal finishing line. d. Designed the path of insertion of the crown. e. Set the output parameter of the crown. f. Designed the preliminary morphology of the crown. g. Used the deformation method to fine-tune the crown. h. The finished crown design.

results, using a statistical software package (JMP® 10.0.0, JMP Statistical Discovery LLC, Cary, NC, USA).

Results

The internal gaps of the crowns made by different methods were list in Table 1. The internal gaps of the crown set on the right maxillary central incisor were among 68.27 $\pm$ 41.01 to 89.80 $\pm$ 30.93 μm. As the reserved cement space setting became larger, the internal gaps slightly decreased, but there was no significant difference among groups 1,2 and 3(One-Way ANOVA, $P > 0.05$). The crowns designed by built-in programming or technician did not affect the internal gap (two-sample t-test, $P > 0.05$).

The internal gaps of the crowns at different surfaces were among 67.39 $\pm$ 21.08 to 114.22 $\pm$ 29.39 μm (Table 2). The largest internal gap of the crowns was located at palatal surface. The internal gap of the crowns at distinct surface had significant difference (One-Way ANOVA, $P < 0.05$). Further analysis revealed the gap located at the palatal surface was significant larger than that located at the labial, mesial, and distal surfaces (Tukey's HSD test).

Discussion

The AR dental simulator system was developed to assist dental students and specialists in self-learning clinical skills. Its purpose was to reduce reliance on full-time dental teachers and provide objective scores after training. It stands as the most comprehensive and accurate training and evaluation system for AR digital dental clinical training courses. A good AR digital dental simulator usually includes briefing, simulation, feedback, debriefing, reflection and evaluation.[12] Through AR digital dental training system, these students' knowledge gain and satisfaction seemed to justify the time, effort and equipment.[13] The students think the training system can improve the dental skill training than conventional method.[10,14] So these AR/VR technology will play an important role in the future of dental education.[15]

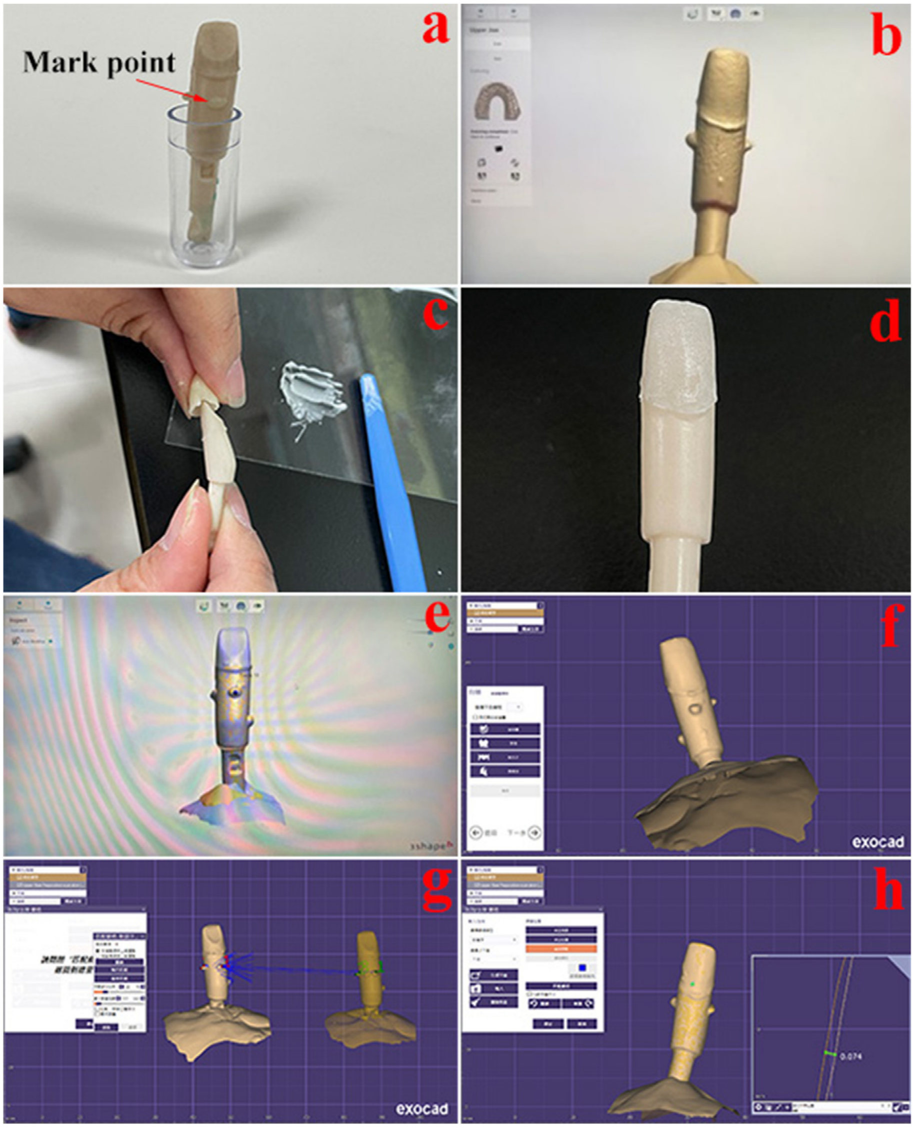

Figure 3 The method for evaluating the internal gap of the crown. a. The mark point. b. Scanned to establish the accurate morphology. c. Fit-Checker® was placed into crown and cemented. d. The tooth was covered by a film of Fit-Checker®. e. The image file of the tooth covered by Fit-Checker®. f. Image imported to EXOCAD software. g. Imported the two image file. h. Measured the distance between the outline of the two graphs.

SimEx, the latest iteration, is a comprehensive digital dental training system with an integrated multi-disciplinary dental curriculum. The optical position system provides three-dimensional real-time accurate feedback of optimal teeth's angle, depth and abundant software lessons. It encompasses operative dentistry, prosthodontics, pediatric dentistry and integrated CAD/CAM digital prosthetic design, offering a complete dental education training program. It was found SimEX education and evaluation system facilitates student self-learning, and this system was very useful for continued study and clinical skill training for dentists, especially for students and junior dentists with high usability satisfaction.[12]

Our findings indicated that the EPCAD software, when integrated into the SimEx-Plus system, provided superior performance in several key areas. The comprehensive software capabilities offered a wide range of design options and intuitive user interface. The ability of precision milling could produce highly accurate crowns that meet clinical standards. The wide material compatibility supported various dental materials for different clinical needs. The efficient processing speed could reduce time from scan to final prosthesis. These advantages made EPCAD software and the SimEx-Plus system a robust combination for modern dental education and practice, enhancing the training experience for students and improving clinical outcomes.

In this study internal gaps of the crown were among 68.27–89.80 μm. The internal gap reported in the literature ranged 23–110μm[16,17], so our study showed the good result. As the reserved cement space setting became larger, the internal gaps lightly decreased. The result was consistent with Sultan et al.'s study.[18] In tooth crown, die spacer was widely used for providing a uniform space for luting cement.[19,20] The recommend cement space for the

Table 1 The internal gaps of the crowns made by different methods.

Group	Distal S	Mesial S	Labial S	Palatal S	Incisal S	Mean	SD
1	57.00	37.67	40.67	148.67	57.33	68.27	41.01
2	65.00	126.00	28.67	136.00	58.33	82.80	41.33
3	72.33	53.33	77.67	77.00	117.67	79.60	20.99
A	86.33	61.33	54.33	126.00	101.33	85.87	26.25
B	90.67	67.67	93.00	80.67	71.67	80.73	10.02
C	33.00	81.00	110.33	117.00	107.67	89.80	30.9

Unit: μm; S, surface; SD, standard deviation; Groups 1, 2, and 3, the crowns were designed in the same way, but they had the different setting space for cement when digital exporting by milling machine. The setting space for Groups 1, 2, and 3 were 0.08 mm, 0.06 mm, and 0.05 mm, respectively. Groups A, B, and C, the crowns were designed individually that each one had some differently slight adjustment but the crowns had the same output setting for cement.

Table 2 The internal gaps of the crowns at different surfaces.

Surface	Distal	Mesial	Labial	Palatal	Incisal
Mean	67.39**	71.17**	67.44**	114.22**	85.67
SD	21.08	30.50	31.59	29.39	26.46

Unit: μm; SD, standard deviation. The symbol '**' indicates significant difference among the groups ($P < 0.01$).

casting full coverage crown known as film thickness was about 25 μm.[21] However, no standardization has been established yet for the CAD/CAM crown about the reserved cement space setting. The reserved cement space setting for implant crown was suggested 60 μm in the literature.[18] In our study, it showed the smallest internal gap about Group 1 that the reserved cement space setting was 80 μm. The different data might come from the software program type.[22]

The crowns designed by built-in programming or technician did not affect the internal gap (two-sample t-test, $P > 0.05$). There was no significant difference between the two different designed methods, which meant that the EPCAD software had complete functions to produce crowns suitable for clinical use.

The internal gap of the crowns at different surface were among 67.39—114.22 μm. The largest internal gap of the crowns was located at palatal surface. The maxillary central incisor has a palatal fossa with an obvious curvature at palatal side. Generally speaking, the accuracy at the curved appearance would decrease when using the CAD production method. Drill size and cutting angle might be the reason. Although the values of the internal gap at the incisal surface were not significantly different from that at the buccal, mesial and distal surface, the slighter larger values still showed that cutting the relative small space would be affected by the drill size.

The traditional methods of making dental crowns requires a period time of fabrication On the other side, when using CAD to plan the morphology of the tooth, there are templates that can provide a rough outline of the teeth and then modify appearance finally. The crowns designed by the wax technique presented non-anatomic form and excessive easily in the literature. The entire CAD design process can be shortened and requires less technical complexity for dental students to practice easily.[23] Nowadays, students have been exposed to 3C products since childhood. The use of computer-assisted teaching in preclinical program is not only easy to get started, but also has a greater motivation for students to learn.

Within the limited data from this study, the new software EPCAD that was integrated within the SimEx-Plus AR simulator could design restorations, and the designed restorations had good internal gap for clinical use. We concluded that students can learn tooth preparation and digital restoration fabrication using the SimEx-Plus AR simulator.

Declaration of competing interest

The authors have no conflicts of interest relevant to this article.

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