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Application evaluation of virtual reality technology in dental implant training: a new dental implant training system

A CONSORT-compliant trial

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Abstract

To evaluate the application of virtual reality technology in a dental implant training system.

A 3-dimensional model of mandible was established by *Mimics17.0* software based on the Digital Imaging and Communications in Medicine data obtained from cone beam computed tomography scanning of the patient in mandibular. Thirty physicians were divided into 2 groups. The virtual reality dental implant training system was used for group A, while conventional theoretical knowledge training and clinical demonstration were performed in group B. All young physicians have a 1-month study. After training, all the physicians in groups A and B would conduct a questionnaire survey according to the training situation, which was compared between the 2 groups. The success rate of the operation was also evaluated and compared.

The median scores in the 5 dimensions of postoperative assessment of group A was 9/9/9/8/8, and of group B was 6/7/6/7/7. The scores of the 5 dimensions were significantly higher than those of group B ($P < .05$), indicating that group A has a better grasp of the simulator. After the training of simulated mandibular implants in group A, the deviations in the 4 dimensions of mesiodistal, buccal and tongue, depth, and angle were significantly lower than those of group B ($P < .05$). Group A has smaller deviations in each of the 4 dimensions than those in group B, indicating group A has a higher operation success rate.

We independently develop a set of virtual surgery system for dental implant training, which can be used for teaching and training, with good operability and predictability, to achieve a breakthrough in dental implant surgery training.

Abbreviations: 2D = 2-dimensional, 3D = 3-dimensional, CBCT = cone beam computed tomography, DICOM = Digital Imaging and Communications in Medicine, VR = virtual reality.

Keywords: dental implant, digital model of jaw, surgical training, virtual reality

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Approved by the Ethics Committee of the Affiliated Stomatological Hospital of Fujian Medical University. Participants have provided their written informed consent to participate in this study.

Consent for publication is not applicable.

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The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

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1. Introduction

Oral implantology is an interdisciplinary subject covering multidisciplinary knowledge with unique theoretical knowledge and clinical operating skills. Therefore, oral implantology education is divided into university education and postgraduation education. In university education, oral implantology courses based on ability training mostly adopt evidence-based medicine, including analysis and discussion based on oral implant problems, cases, and patients. Clinical teaching and basic operation training are performed in postgraduation education. After years of learning in traditional lecture teaching, students have poor ability to practice independently and use knowledge flexibly in evidence-based medicine. Moreover, the students participating in the continuing education clinical implantation training courses have varying levels of basic implantation knowledge. Due to time and space constraints, they mostly focus on case explanations and operation skills training. Generally speaking, in the context of traditional medicine teaching, it is necessary to explore a clinical teaching model of oral implantology suitable for students to train qualified dental implant physicians.[1]

Virtual reality (VR) technology is a scientific method and technology created by human beings in exploring nature.[2] VR technology is interactive, immersive, and conceptual, which can build a virtual surgical system performing pre-operative rehearsal or operation exercises. At present, virtual surgery has been widely used in craniomaxillofacial bone reconstruction in the field of stomatology and navigation of oral surgery.[3,4] The virtual environment training in surgical simulator has a vivid sensation, which enables the operator to practice surgical skills and receive objective evaluation.[5] Hence, this study aimed to establish a mature simulation of surgery operation training system by self-developed implant surgery simulation system of clinical surgery operation training for doctors or medical students.

2. Materials and methods

2.1. Case selection and data acquisition

This study was approved by the Ethics Committee of the Affiliated Stomatological Hospital of Fujian Medical University. Three adult patients who meet the indications for conventional implants were selected from the imaging database of the Stomatological Hospital of Fujian Medical University. The informed consent was obtained from all the participants.

A total of 3 mandibular models with different tooth positions distributed in 3 arch regions of the mandible (anterior teeth, premolars, and posterior teeth) underwent the first-stage oral implantation operation as a reference model for establishing a virtual implant training system.

2.2. Selection of the subjects

Thirty young physicians and graduate students in rotation or advanced studies in the undergraduate room from September 2018 to December 2019 were selected as experimental subjects. The informed consent was obtained from all the participants. They were divided into groups A and B, with 15 people in each group. After training, all physicians master oral implantation before the experiment.

Based on conventional theoretical knowledge training and clinical practice, the VR dental implant training system was used for training in group A as the experimental group. Conventional theoretical knowledge training and clinical demonstration were performed in group B as the control group. All young physicians have a 1-month surgical study (Fig. 1).

2.3. Equipment and software settings

NewTom GiANO cone beam computed tomography (CBCT) (QR s.r.l. Co., Ltd., Silvestrini 20,37135, Italy), Mimics 17.0 (Materialise Co., Ltd., Belgium), 3ds Max 2014 (Autodesk Co., Ltd.), Unity 3D (Unity Technologies Co., Ltd.), HTC vive helmet and its matching handle (HTC Co., Ltd., China), Straumann implant surgical toolbox (Straumann Co., Ltd., Switzerland) (Fig. 2). CBCT scan: continuous, no interval, no overlap; layer thickness is 0.15 mm, the voxel is 0.15 mm, image size was 512×512 pixels, 90 kV, 4 to 8 mA. The scanning datum plane was parallel to the orbital ear and perpendicular to the horizontal plane. Scanning range: $11 \times 8\,cm^2$ from the inferior orbital edge to the inferior hyoid bone. The data output format was Digital Imaging and Communications in Medicine (DICOM), and it was stored in the computer system disk. We downloaded the surgical toolbox manual and product manual from the Straumann official website on the computer system disk.

2.4. System structure design

The digital model includes the basic configuration of the operating room and commonly used surgical instruments.[6] When virtual surgery is in progress, the operator needs to press the handle button to achieve the picking action and feel the components' existence and movement. Therefore, the interactive software Unity 3D 5.5.1 adds steel parts to the surgical instrument model to realize movement and collision's physical functions. To simulate the interaction between surgical instruments and the virtual mandible, we added the collision detection function. To further increase the virtual surgery system's utilization rate, the system should set a window button "add configuration" for users. In the face of different needs, users can add digital models of required appliances or change case models in the background. Module configuration was performed in Figure 3.

2.5. Three-dimensional reconstruction

The purpose of image binarization was to distinguish the foreground and the background. It set the gray value of all pixels of the image to 0 or 255,[7] reducing unnecessary data, making the image black and white, and highlighting the target contour.[8] We imported the DICOM data of the CBCT image in the Mimics 15.0 interface. We performed image binarization under the bone window to remove the interference of soft tissues, acquiring

Figure 1. Trainees train in a virtual reality scene. (A) Trainees wear helmets for training; (B) Virtual reality scene.

Figure 2. HTC vive helmet and its matching handle.

complete jaw bone tissue image. The 3-dimensional (3D) reconstruction of jaw tissue was performed through the 2-dimensional (2D) processing of region cutting and filtering and the 3D processing of image segmentation and slice reconstruction. In the preliminarily built 3D model, after creating a mask, the mandible was selected for region growing and Boolean operation, which separated the mandible from other bone tissues. We set the separated mandible image and performed a 3D calculation to obtain a mandible virtual model (Fig. 4). We imported the DICOM data of the CBCT image in the Mimics 15.0 operation interface and performed binarization, setting the gray value (Hounsfield unit, HU) to 1200 HU to remove the interference of soft tissues. Following the mandibular canal, the mandibular canal's trajectory model was established through steps such as creating a mask. Binarization was performed again, and the gray value was set to 260 HU. At this time, the image showed a soft tissue shadow. The soft tissue shadow trajectory model of the inferior alveolar neurovascular bundle in the mandible canal was established by creating a mask. After performing Boolean operations on the above 2 models, 2 exact virtual models of the mandibular canal were obtained (Fig. 5). Observation and measurement of specific data such as the length, inner and outer diameter, pitch, number of threads of various tools were conducted. 3D digital models of various tools were obtained in the 3ds Max 2014 software through the data combined with the product manual provided by Straumann (Fig. 6).

Observation and movement were performed through changes in the spatial position of the helmet and handle. We add movement and collision functions for surgical instruments that require free movement. The digital craniomaxillofacial model only has a more nuanced relationship between the mandible and the surgical instrument, so it is necessary to keep the models other than the mandible in a static state. Then, we add hinge joints and collision detection for both the virtual mandible and the virtual mandibular canal.[9] Due to the small size of the oral implant, clarity of imaging and the computer's operating speed when preparing the implant socket, it is planned to implant the oral implant with $\phi = 4.1$ mm and $L = 10$ mm. The implant socket detection block is divided into 3 sections along the axial direction and 3 sections along the horizontal line, accounting for 9 detection areas (Fig. 7). The mandible was buried in: 3 detection blocks matching the diameter of the ball drill ($\phi = 1.4$ mm, 2.3 mm, 3.1 mm); 3 collision detection blocks matching the diameter of the reaming drill ($\phi = 2.2$ mm, 2.8 mm, 3.5 mm); 3 detection blocks matching the oral implant diameter ($\phi = 4.1$ mm) within the depths of 6 mm, 8 mm, and 10 mm, respectively. After reaching the pre-determined depth, the handle stopped vibrating.

Clinically, the surgical instruments were also affected by gravity. We imported the model built on 3ds Max into Unity 3D 5.5.1, selected it and used the 'Add Component' option in the 'Inspector' tab to add rigid bodies to the necessary surgical instrument models and checked the 'Use Gravity', adding gravity to the surgical instrument model. When the collision detection system on the surface of the virtual mandibular tube collided with other components, the script written in Unity 3D software ran

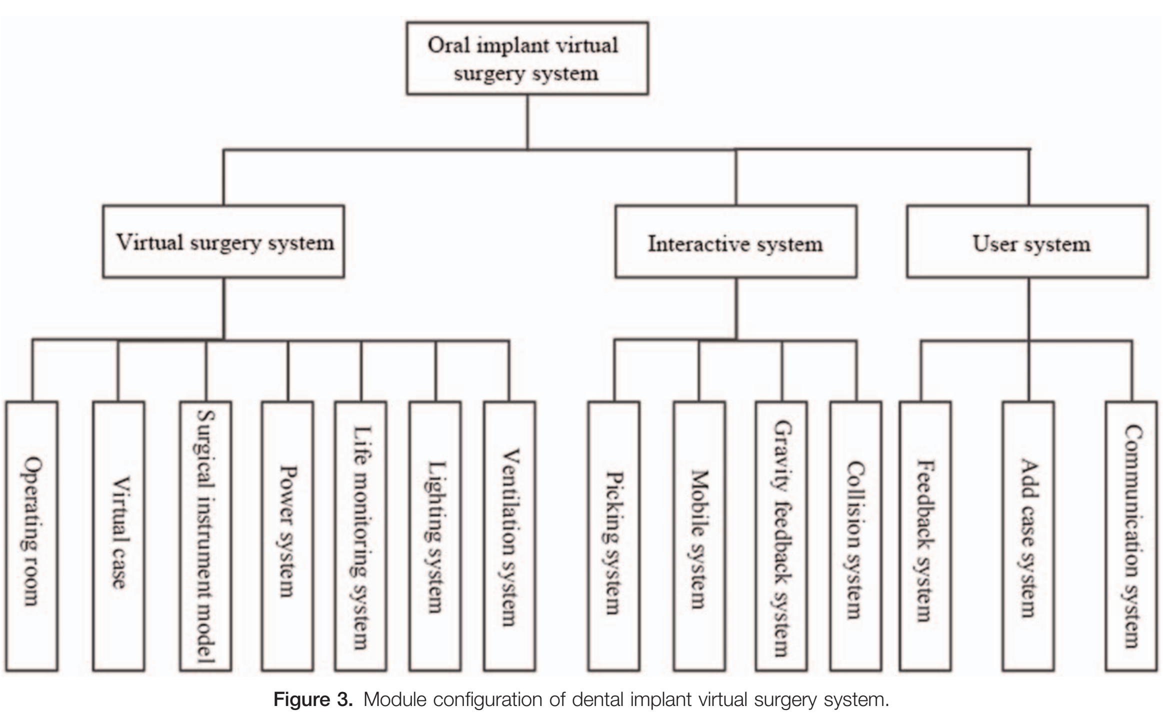

Figure 3. Module configuration of dental implant virtual surgery system.

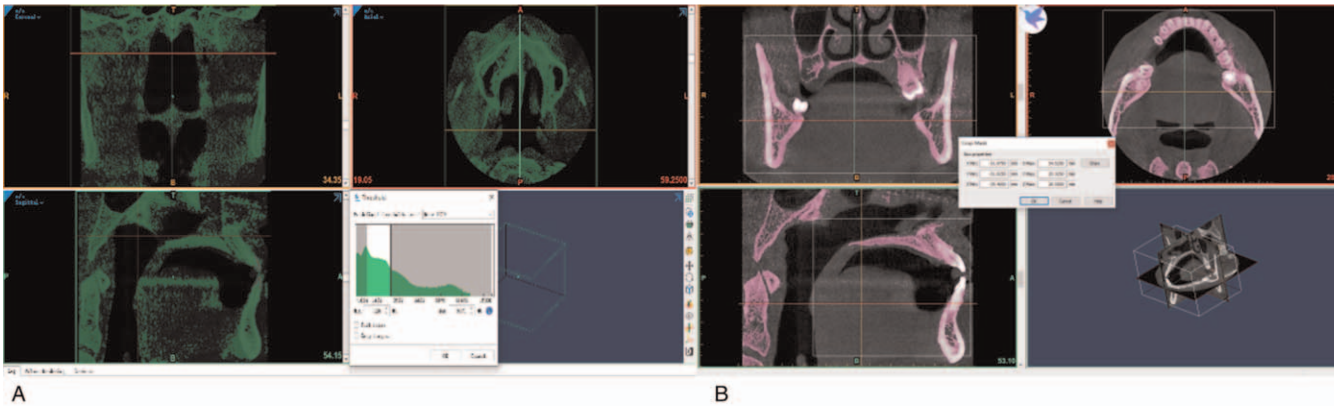

Figure 4. Preliminary establishment of the 3D model. (A) Select bone window and create mask; (B) Local growth. 3D = 3-dimensional.

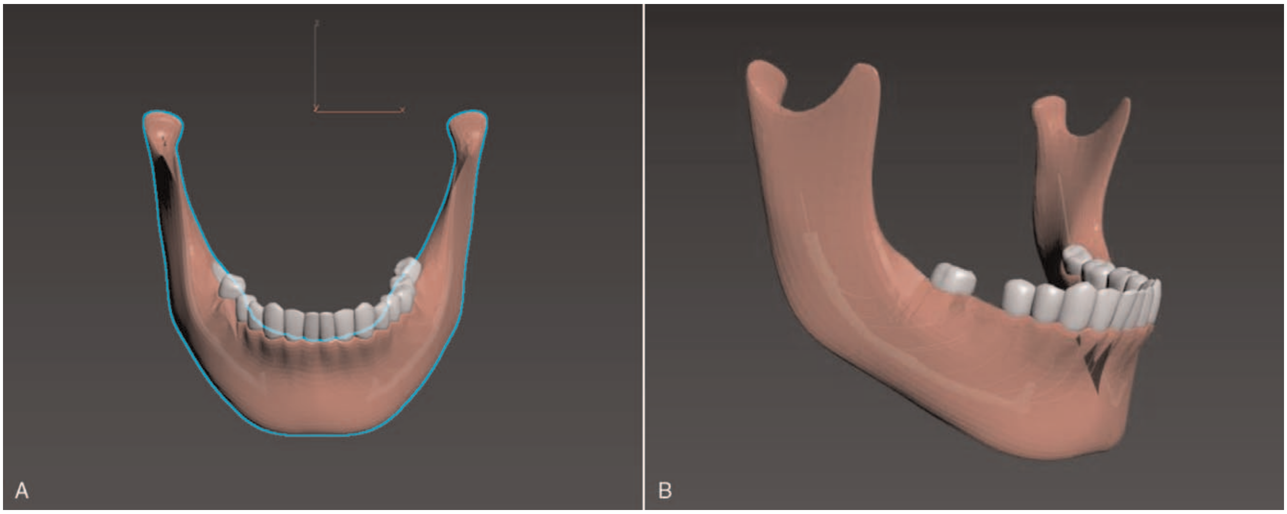

Figure 5. 3D model of mandible and mandibular canal. (A) Coronal bitmap; (B) Right front bitmap. 3D = 3-dimensional.

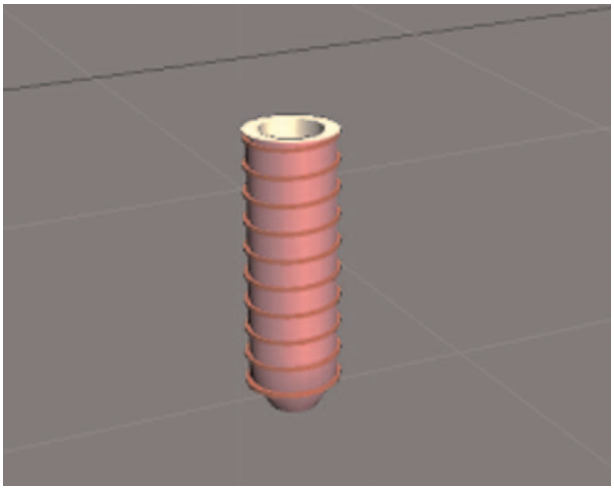

Figure 6. The virtual image of the Straumann BL implant with 3ds Max 2014 software (ϕ4.1 mm, L10 mm).

immediately and emitted an audible warning to realize the function of reporting errors.

After pressing the handle button to start the system, the animation showed that the mucosal bone flap is opened to expose the implant site. Then, we moved the virtual hand close to the surgical instrument table and pressed the button to select and replace the instrument (Fig. 8). The machine head was conducted to select a virtual ball drill to smooth the alveolar crest. After the ideal position was confirmed, we used the ϕ2.2 mm–2.8 mm–3.5 mm virtual reamer to complete the preparation and the same diameter virtual indicator rod to check the axial direction. The neck forming drill was used to expand the surgical approach, and the tapping drill was used to form threads to complete the implant socket's preparation with a depth of 10 mm (Fig. 9). We pressed the handle button and used the carrier with the Strauman BL implant (ϕ4.1 mm L10 mm). Then we pressed the button and moved the implant, released the button when it reached the implant site. After the implant dropped to the prepared implant socket, we screwed the healing abutment on the implant with a screwdriver (Fig. 10). After the first 2 operations were conducted,

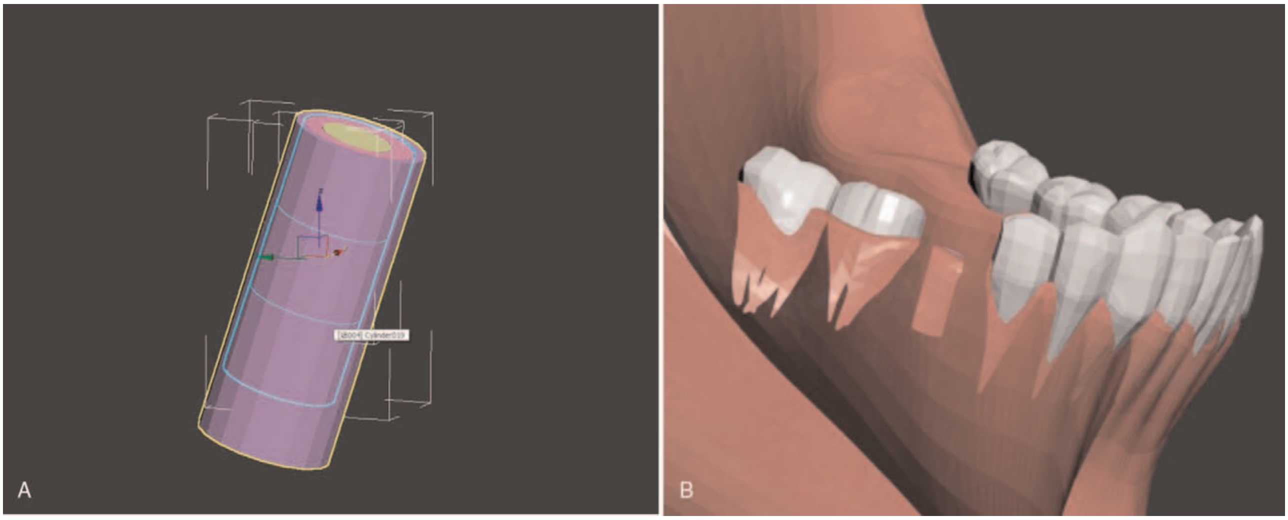

Figure 7. Schematic diagram of virtual 3-stage collision detection block. (A) Implant socket collision detection block; (B) Impactor embedded in the mandible.

we moved the handle and clicked the finish button on the interface to display the stitching animation. At present, this project team's equipment cannot meet the accuracy requirements of suture simulation, and the operation of suture has not been realized temporarily. It will be improved in the next phase of the experiment.

2.6. Evaluation methods

2.6.1. Subjective evaluation.

After training, the physicians in groups A and B would conduct a questionnaire survey according to the training situation. This questionnaire was aimed at the fidelity and user-friendliness of the simulator, and other questions were designed according to the detailed surgical procedure.[5] The

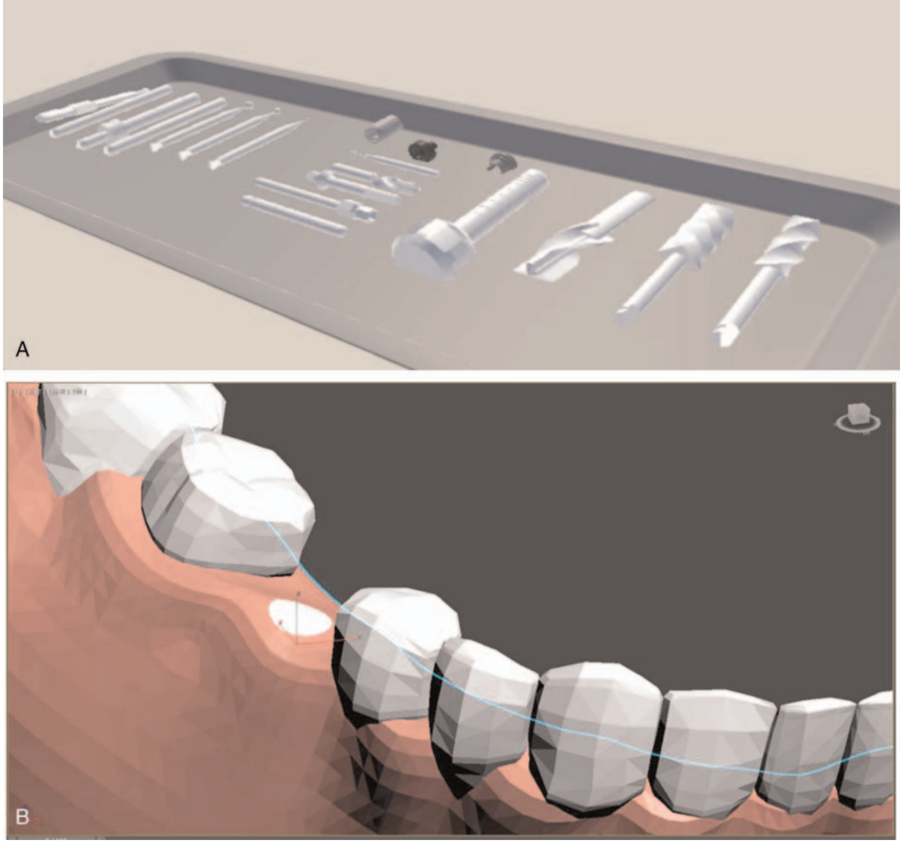

Figure 8. Schematic diagram. (A) The virtual instrument table; (B) Implant site of the right mandibular first molar.

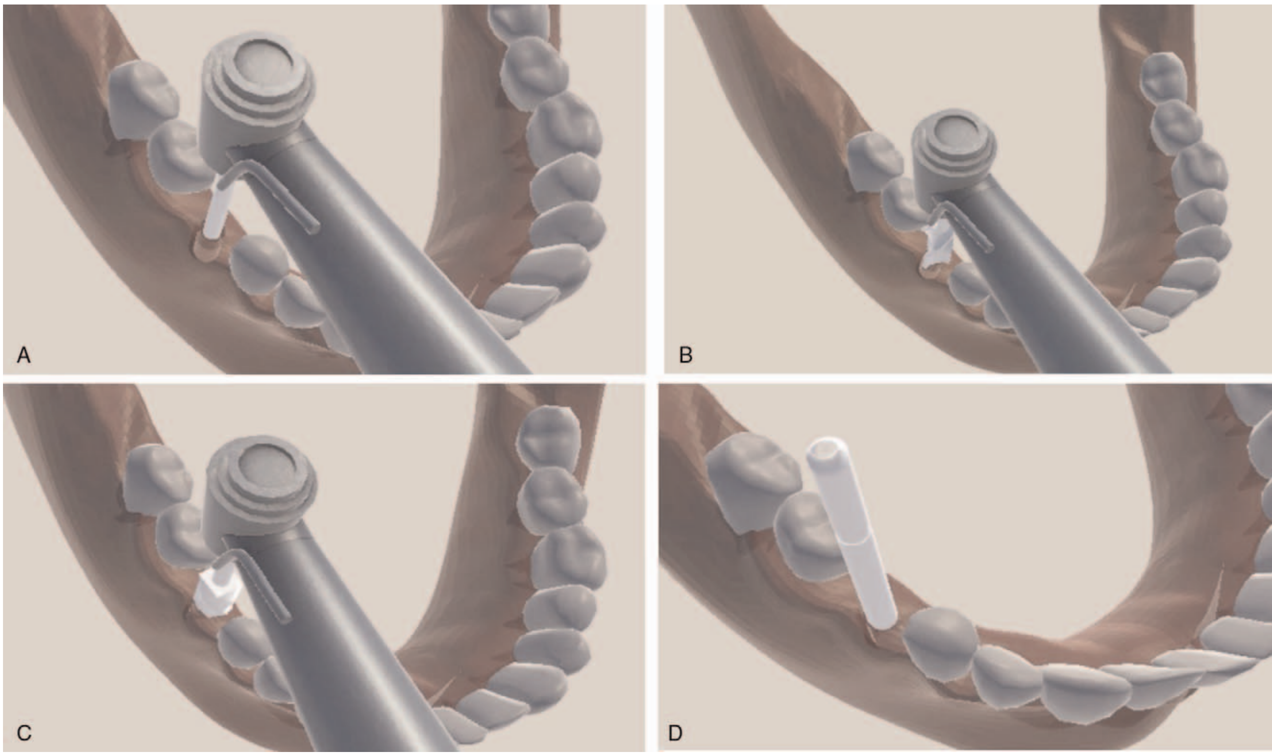

Figure 9. Virtual implanting process. (A) Ball drill fixed point; (B) reamer preparation; (C) tapping drill tapping; (D) measuring rod detection.

questionnaire contained the following 5 individual items. Each item was evaluated with a full score of 10: ① Mastery of the anatomical structure; ② Clarity of the surgical vision; ③ Space experience of cavity preparation; ④ Sense of implant placement; ⑤ Mastery of implantation process (Table 1).

2.6.2. Objective evaluation. All 30 young physicians performed 3 simulated implant operations on each tooth position in 3 dental arch areas. Perception-based evaluation through questionnaire surveys was imprecise and limited. Wang et al[10] designed a comprehensive evaluation method, including qualitative and quantitative analysis. In the quantitative evaluation method, the quantitative indicators needed to be defined for the key surgical parameters, and the performance of the simulator could be quantitatively analyzed through comparison. Computer recording the implant's 3D position in the mesiodistal, buccal, and tongue, depth, and angle deviations within 1 mm or 5° were recorded as a success, while within 1 mm or more than 5° were recorded as failures.

Figure 10. Implant placement.

2.7. Statistical analysis

SPSS 21.0 software (IBM Inc., Armonk, New York, USA) was conducted for statistical analysis. The 5 dimensions of scoring conditions and the corresponding skewness and kurtosis P value of the mesiodistal in the simulated surgical operation deviation were all higher than 0.05, indicating that the data were not normally distributed. Normally distributed measurement data were represented by ($x \pm s$). An independent sample t test was used to compare differences; non-normally distributed measurement data were described by interquartile range, and the rank-sum test was used to compare differences. $P < .05$ is considered statistically significant.

3. Results

3.1. Subjective evaluation

From Table 2, it can be found that the scores of groups A and B in the 5 dimensions have significant differences after surgery ($P < .05$). The median in the 5 dimensions of group A was 9/9/9/8/8, and of group B was 6/7/6/7/7. The scores of all 5 dimensions of group A are higher than those of group B, indicating group A has a better grasp of the simulator.

Table 1

Quantitative scores table (scores).

	Very bad	Bad	Average	Good	Excellent	Total
Mastery of the anatomical structure	1–2	3–4	5–6	7–8	9–10	
Clarity of the surgical vision	1–2	3–4	5–6	7–8	9–10	
Space experience of cavity preparation	1–2	3–4	5–6	7–8	9–10	
Sense of implant placement	1–2	3–4	5–6	7–8	9–10	
Mastery of implantation process	1–2	3–4	5–6	7–8	9–10	

Table 2

Questionnaire scores of group A and group B after training (scores, $\bar{x} \pm s$).

Variability	Mastery of the anatomical structure	Clarity of the surgical vision	Space experience of cavity preparation	Sense of implant placement	Mastery of implantation process
Group A	9 (8,10)	9 (8,9)	9 (8,9)	8 (7,9)	8 (8,9)
Group B	6 (5,7)	7 (6,7)	6 (6,7)	7 (7,8)	7 (6,8)
Z value	−4.483	−4.695	−4.542	−2.833	−3.497
P value	.000	.000	.000	.005	.000

3.2. Objective evaluation

After the training of simulated mandibular implants in group A, the deviations in the 4 dimensions of mesiodistal, buccal and tongue, depth, and angle were lower than those of group B, and the differences were statistically significant ($P < .05$). The results showed that group A has smaller deviations in each of the 4 dimensions than those in group B, indicating group A has a higher operation success rate (Table 3).

4. Discussion

Teaching is a natural process for learning from the perspective of education, and it has always been the inner root. Learning can only be enhanced through teaching. Therefore, in addition to improving knowledge through teaching, there are other technologies to enhance physicians' or medical students' delivery of information. Dental diagnosis and treatment are not natural phenomenon, and they are not suitable for online course work. Because online courses tend to be language and symbol courses like mathematics, stomatology is characterized by practical skills, which are best learned through a tutorial system. VR is an excellent way to guide a series of precise actions. VR allows continuous tracking of all hand movements with sub-millimeter precision practical learning. VR has been used to provide training in many fields. VR will enable schools to create virtual presentations, simulating medical places, and patients. Clinically, medical units cannot increase the chance of learning and practice through endless dental scenes.[11] In this study, the results demonstrated that the VR dental implant training system has higher scores in the 5 dimensions of postoperative assessment, indicating a better grasp of the simulator.

In clinical terms, oral implant teaching supplies are expensive and lack reusability. Students can only become familiar with operating skills through non-clinical practice training, such as watching operating videos and observing teachers' clinical teaching. Those methods lack practical clinical experience and cannot meet clinicians' skills in actual work. The clinical demand for oral implants is large. There is a shortage of professional talents, and the operation level of the surgeon is relatively high. Due to the shortcomings of non-reusable and expensive parts of the existing oral implant training practical instruments, the application of VR technology to the training of oral implant surgery has certain advantages. This experiment combines oral implants with VR technology. It uses the simulation of VR technology to avoid waste of physical materials, which is environmentally friendly and improves systematic, fault-tolerant, and interesting learning. Our results showed that the VR dental implant training system has lower deviations in the 4 dimensions of mesiodistal, buccal and tongue, depth, and angle.

Novice doctors master the skills by observing the operation of experienced surgeons. In medical training, corpses and synthetic materials still play an essential role in training surgery, which may not be repeatable. Due to the shortage of resources, artificial bones or corpses are inefficient and expensive.[12] Digital technology runs through the entire oral treatment process, and its progress has brought brand-new concepts to oral implant education and training, continually changing the traditional model. Cultivating an excellent dentist requires the patient training of incredible mentors and a wide range of cases to provide hand training opportunities.

Moreover, the industry's current teaching environment still mainly uses external teeth and artificial teeth to train dentists' tactile perception ability and operating skills. Studies showed that

Table 3

Deviation of simulated operation in group A and group B ($\bar{x} \pm s$).

Variability	Mesio-distal (Mm)	Buccal and tongue (Mm)	Depth (Mm)	Angle (°)
Group A	0.73 (0.33,0.84)	0.78±0.41	0.61±0.32	6.66±3.87
Group B	0.85 (0.71,1.32)	1.12±0.38	0.89±0.24	9.68±3.74
Z/t value	−2.012	−2.379	−2.705	−2.176
P value	.044	.024	.012	.038

future oral courses would benefit from the long-term inclusion of virtual practice exercises.[13,14] Students need to be exposed to more virtual patient cases to improve their clinical ability. Therefore, it is of great significance to design a practical system that uses VR technology to cultivate planting ability.

A previous study has assessed orthodontic residents' performance and attitudes when treatment planning orthognathic surgery cases using 2D digital, 3D digital, and VR surgical simulations and demonstrate that simulation methods of increased fidelity (3D and VR) are appropriate alternatives to 2D conventional orthognathic surgical simulation methods when combined with traditional records,[15] which was in accordance with our results. Another study on education during surgical procedures and related clinical anatomy in a VR workspace showed that use of VR technology with a live communication tool could be an alternative teaching method and its overall advantages are a closer look at the slides/monitor and concurrent observation of the multiple assets in various directions by multiple attendees.[16]

There were still some limitations in this study. First, some physicians reported that they felt dizzy after wearing a helmet for a certain period during the simulated operation. Second, during the reaming process, because 9 collision detection blocks were embedded in the mandible in advance, and the script that the detection module disappeared immediately after being triggered by other objects was written in the background, the diameter and depth of the hole cannot be controlled by the operator at will. Third, the virtual actions of incision, flapping, and suture were not realized, and the intra-operative bleeding had not been simulated. These actions required higher precision of virtual activities, the faster image loading speed of the computer, and accurate simulation of the opponent's movements. At present, the simulation of subtle hand movements is one of the most challenging problems to overcome. Forth, the mandible is opaque and has a reaction force to the operating object. Moreover, even if a rigid plug-in is added to the virtual mandible in the virtual, it cannot exert a reaction force on the operating object and give feedback on the operator's hand feeling. The manufacturer uses the virtual tool model in computer haptics visualization and interactive in 3D (CHAI 3D)[17] when developing the simulation platform. The software uses only 1 proxy point for collision detection. The disadvantage is that geometric topological interference will occur during the collision of objects, which leads to the phenomenon of bones crossing the tool during the mandibular surface splicing process, and lack of force feedback to the operator.[18] To overcome this limitation, we should pay more attention to the force feedback platform. Fifth, due to the limitations of the VR technology itself in image loading, the image resolution is low, and sometimes part of the image overlaps. VR is currently a new visualization technique, so there was no evaluation on the effectiveness of VR-based technology. It is hard to offer an overall conclusion of the efficacy of these strategies. The cost of setup and maintenance of the VR-based intervention has not been evaluated. Further research should evaluate the effectiveness of VR in a variety of settings and evaluate outcomes such as attitude, adverse effects, and cost-effectiveness.

5. Conclusions

This project group's implant surgery simulation system can be used for clinical operation training, aiming to establish a mature simulation of surgery operation training system through digital simulation of some complex operations. In the future, it can be used for physicians or medical students' daily surgical operation training, practice assessment, physician assessment, and other practical activities, even for remote medical education and clinical case communication, improving the effect and efficiency of oral implant treatment.

Author contributions

YZ, WLC, XXZ, and JC for research design and writing. BWH, WXH, and DW for the digital model establishment and experimental operation. WLC, XXZ for statistical analysis.

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Visualization: Xiaoxian Zhao, Bingwei He.
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Writing – review & editing: Yong Zhou, Wanlu Chen, Xiaoxian Zhao, Bingwei He, Wenxiu Huang, Dong Wu, Jiang Chen.

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