Comparing between virtual reality based pre-clinical implantation training and traditional learning methods

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ABSTRACT

Objective. As dental implanting becomes an increasing demand among patients with tooth loss, an efficient and effective training for students is to be necessary. In this case, we anticipate the possible application of virtual reality (VR) technology to pre-clinical implantation training (PCIT) in order to improve the students' learning efficiency and effectiveness.

Methods. The study divided 20 subjects into two groups on average—VR based PCIT (experimental group) and traditional PCIT (control group) with the completion of the background survey (BS) before PCITs, to guarantee no apparent backgroud variation including learning of oral implantology and VR technology, learning habits, interests and hobbies, *etc*. All subjects received identical professional tests (T-1, T-2, T-3) before, in and after PCITs to assess the knowledge mastery condition and maintaining levels. Along with both PCITs, the subjective evaluation tests (SET) were distributed to collect the subjective feedback data so as to analyze the preference to each PCIT. Meanwhile the total interaction time, learning duration per subject were recorded for the performance analysis.

Results. The results show that from T-1 to T-2 period, the score of VR based PCIT increased significantly ($p < 0.05$). And the results of SET show that subjects in VR based PCIT generally obtain over one score higher than the ones in traditional PCIT as for the items of "Convenience", "Interest", "Comfort", "Confidence" and "Subjective initiative" except "Precision". During both PCITs, VR based PCIT shows a shorter learning duration and sufficient one-on-one interaction opportunities.

Conclusion. Compared with traditional PCIT, VR based PCIT has obvious influence on enhancing students' knowledge mastery, study willingness and learning efficiency.

Subjects Dentistry, Science and Medical Education

Keywords VR based PCIT, Virtual reality, Implantation training

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INTRODUCTION

With the rapid burgeoning of worldwide economy and maturing oral implanting technology, the implant dentures have entered the worldwide market and become the preferred choice for many patients (*Londoño et al., 2021*). However, owing to the relatively small number of dentists, where only 11% are qualified for oral implanting, the per capita ratio does not reach the appropriate standard. Under the circumstances where the increasing needs of oral implanting contributes positively to the high requirements of

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dentists in implanting (*Alghamdi & Jansen, 2020*), there exists the substantial necessity for the development of pre-clinical implantation trainings (PCITs). In the process of oral implantology learning, systematic and comprehensive PCITs serve not only to enhance the confidence of students before confronted with the real clinical surroundings, but achieve a smooth transition from theory-based education to clinical practice.

At present, the common training system prefers the traditional PCIT (a theory-practice combined system consisting of theory teaching by professors and following self-practice on a head simulator) (*Zhou et al., 2021*). The teacher-student teaching method enables a preliminary understanding of implanting procedure, but it also illustrates several restrictions in the long run (*Lee & Chiu, 2022*; *Mintz, Pierson & Miller, 2022*; *Pien et al., 2022*; *Eidt, 2023*). (1) The disability to simulate actual circumstances of oral cavity; (2) lacks of a good time regulation, flexibility and repeatability; (3) subjective judgment makes the quantitative evaluation and objective feedback hard to achieve; (4) insufficient supervision on each student. In this case, study on how to compensate for the disadvantages of traditional PCIT and optimiaze the quality of it has become a focus.

Within recent years, virtual reality (VR) stepped foot in wide range of fields, and under the help of VR technology, we are able to witness a promising pain control strategy for various pain conditions (*Viderman et al., 2023*) including labor (*Frey et al., 2019*), cancer pain (*Zeng et al., 2019*), chronic back pain (*Grassini, 2022*), *etc.* Besides, a combination of current state-of-the-art computer and imaging technologies has the potential to be a revolutionary technology in many surgical fields (*Sun et al., 2023*). Additionally, medical education becomes one of the heating targets owing to it's hazard and cost (*Savir et al., 2023*). Recently, with the development of medical technology and the predictable trend of multidisciplinary integration, the combination of medicine and VR technology have been applied in different disciplines, including anaesthetic training (*Zafar et al., 2021*), nursing (*Liu et al., 2023*), anatomy learning (*Da Cruz Torquato et al., 2023*), *etc.*, among which, VR based PCIT is also a classic revolution in the application of VR technology in the education of oral dentistry (*Zafar et al., 2020*; *Ogawa et al., 2011*; *Azhari et al., 2024*; *Yan et al., 2023*; *Barros Padilha et al., 2023*).

As study shows, VR based PCIT enables an immersive experience *via* multi-sensory approaches for students and enhances the sense of engagement and subjective initiative (*El Beheiry et al., 2019*). However, research related to the combination between oral implantology and VR technology, especially comparison with traditional PCIT, remain quite a few. In this case, a comparing research between VR based PCIT and traditional PCIT including time duration, teaching effectiveness and subjective feedback will be intended in order to provide necessary instruction for PCITs.

MATERIALS & METHODS

Research methods

Background survey (BS) and professional test 1 (T-1)

Background survey (BS) and professional test 1 (T-1) were conducted for 20 subjects in both groups. BS covers a wide range of knowledge and conception, including the learning

of oral implantology and VR technology, learning habits, interests and hobbies, *etc.* T-1 consists of 15 fill-in-the-blank questions related to oral implantology, with 1 point obtained for correct answers and 0 points for wrong answers or no answers, 15 points in total.

PCIT

Control group: Ten subjects received traditional PCIT with a teacher-student ratio of 1:5. Professors gave theoretical lectures and explained the basic process of clinical implantation in the first place, then distributed implantation tools, implants and other equipment for self-practice. The training processes including teacher-student interactions and training duration were recorded.

Experimental group: Ten subjects received VR based PCIT on the uniDent simulator. The whole training process is started by the introduction of basic knowledge, including the dental anatomy, catagories of tooth loss, indications and contraindications of implanting surgeries upon various conditions. Then, the instruments from several systems of dental implanting are introduced to the subjects and basic VR practice will be given, such as grinding, locating, axis and vertical lifting. Subjects are able to select different levels and modes from the series of training items in order to enhance the skills related gradually. Finally, a case-by-case study will provide the subjects with a variety of patient-based conditions, which creates the chance to handle different situations. During the PCIT, subjects are allowed to stop the process, ask for tips when encountering difficulties and continue or repeat the previous step. The training process with the interactions and training duration were recorded.

Subjective evaluation test (SET) and professional test 2 (T-2): The SET covers a wide range of items from convenience to subjective initiative. T-2 was distributed to 20 subjects immediately after PCITs. They were asked to choose the score in the spectrum between 1 and 10 under six questions mentioned above, according to their own will and reflections. The 15 fill-in-the-blank questions in T-2 are consistent with the ones of T-1.

Professional test 3 (T-3): Four weeks after the training, 20 subjects were given T-3. The contents of T-3 were the same as the ones of T-1 and T-2, which were filled in and collected.

Data analysis: Collect questionnaires and tests, compare scores in SET under different PCITs in a horizontal way and use statistical methods to analyze the significant difference of test scores among different stages.

Statistical methods

Data were analyzed *via* Prism 10 for MacOS, and the collected data are coped with t-test or two-factor repeated measure ANOVA. Inspection level: $\alpha = 0.05$.

Human participant approval and participant consent

The Stomatological Hospital of Chongqing Medical University granted ethical approval to carry out the study within its facilities (Ethical Application Ref: 2024-026) and every step

of training assessment has obtained both verbal and written consents from all participants involved.

RESULTS

Sample retention rate and background survey results

The study has enrolled 20 postgraduate students in the School of Stomatology, Chongqing Medical University in total with 10 in control group and 10 in experimental group separately. 20 subjects participated in the study from the beginning to the end, including all the assessment surveys (BS and SET) and examination (T-1, T-2, T-3), and the overall sample retention rate was 100%. According to the collected data of BS before PCIT, the results show that there is no significant difference (Fig. 1) among subjects as for their preferred learning approach (paper-free learning/paper-based learning), video game interest, degree of interest in oral implantology and learning confidence ($P > 0.05$).

Results of T-1, T-2 and T-3

Test contents are closely related to oral implantology. As it can be witnessed, from pre-training to training, the score sees a significantly increasing tendency in both PCITs (Fig. 2) ($P < 0.05$, Effect size = 1.55) with the average scores from 3.9 to 9 in VR based PCIT, and ones from 4.3 to 6.2 in traditional PCIT (Fig. 3).

Four weeks after PCITs, test scores from both groups show a following decrease, whereas they still remain a higher level in comparison with those in T-1. Comparing both groups, there is no significant difference between T1s ($p > 0.05$), whereas T-2 scores in VR based PCIT are significantly higher ($q < 0.05$, Effect size = 1.66). Interestingly, although the score drop in VR based PCIT is more apparent from T-2 to T-3 compared with that in traditional PCIT, the average score gaining in T-3 from VR based PCIT is still higher than that in T-2 from traditional PCIT.

Results of subjective evalution test

Along with PCITs, SETs were distributed to both groups and collected afterwards in an anonymous manner. As data generated shows (Fig. 4), both PCITs are able to provide a precise and understandable operation procedure with the same score of 8.7 obtained in the item of "Precision". Whereas in the items of "Interest", "Confidence", "Comfort" and "Willingness", VR based PCIT received significantly higher scores compared with traditional PCIT ($q < 0.05$), among which, the item of "Are you willing to experience corresponding PCITs again?" (Willingness) reaches the most obvious gap with 3.2 points (Table 1). In terms of traditional PCIT, the items of "Convenience", "Comfort" and "Willingness" have relatively low score rating around five, among which, the rating of "Comfort" in VR based PCIT also does not remain an ideal level lower than seven.

Interestingly, among the subjects in VR based PCIT, only one rated "Precision" as over 6 out of 10 and the other rated all items as 10 out of 10. In this case, we compared the three test results from both with average scores in traditional PCIT (Fig. 5). From the chart, it shows a sharp rise from T1 (0 in 15) to T2 (9 in 15) in terms of subject with high rating. On the contrary, scores from the subject with a low rating showed a relative drop by 6 to T3

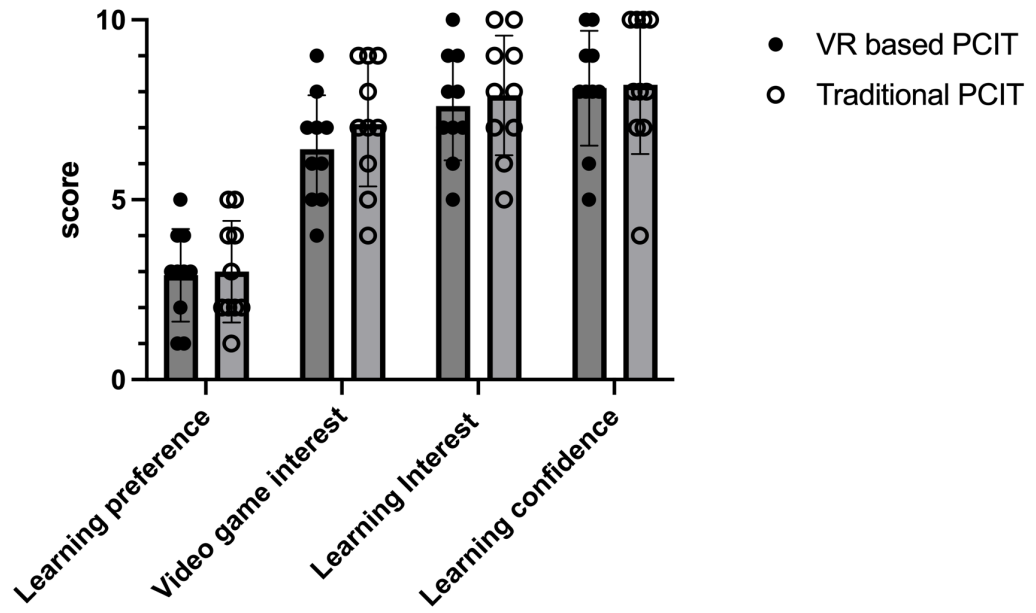

Figure 1 Scores of background surveys before PCITs. The items are ranging from the preference between paper and electronic devices (score: 1 paper-10 electronics), to what extent do you like video games, to what extent do you like oral implantology and the confidence level you have in learning oral implantology.

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(3 out of 10) compared with a 4 in the subject with a high rating. However, both subjects gained higher scores in T2 than the average scores in traditional PCIT.

Specific situation during learning activities

In terms of learning duration, traditional PCIT applies the class-based teaching method, set to four classes period with 3 h in total. Meanwhile, VR based PCIT allows students to finish their VR based PCIT tailored to their individual situation. By recording the learning duration of students in the experimental group, the results show that the average learning duration is 50.3 min (Fig. 6), and the fastest completion is within 38 min. In comparison with the average score in the group of traditional PCIT, the subject completing VR based PCIT within 38 min does not have score drop among all tests (Fig. 7). Quite the contrary, as for the score in T2, the subject within 38 min gained 2.8 higher than that in the traditional PCIT group.

Based on the average learning duration (50.3 min) in VR based PCIT, we compare the test data over 50 min and below 50 min with that in traditional PCIT (Fig. 8). As it can be witnessed, both groups in VR based PCIT show higher average scores than that in traditional PCIT in T2 and T3. Additionally, the score in the group over 50 min is slightly higher than that in the group below 50 min, as indicated in the tests above.

Besides, the recording data of interactions between teachers and students in traditional PCIT shows, that during 3 hours of study, the average interaction times are 7.25 with the highest at nine (Fig. 9).

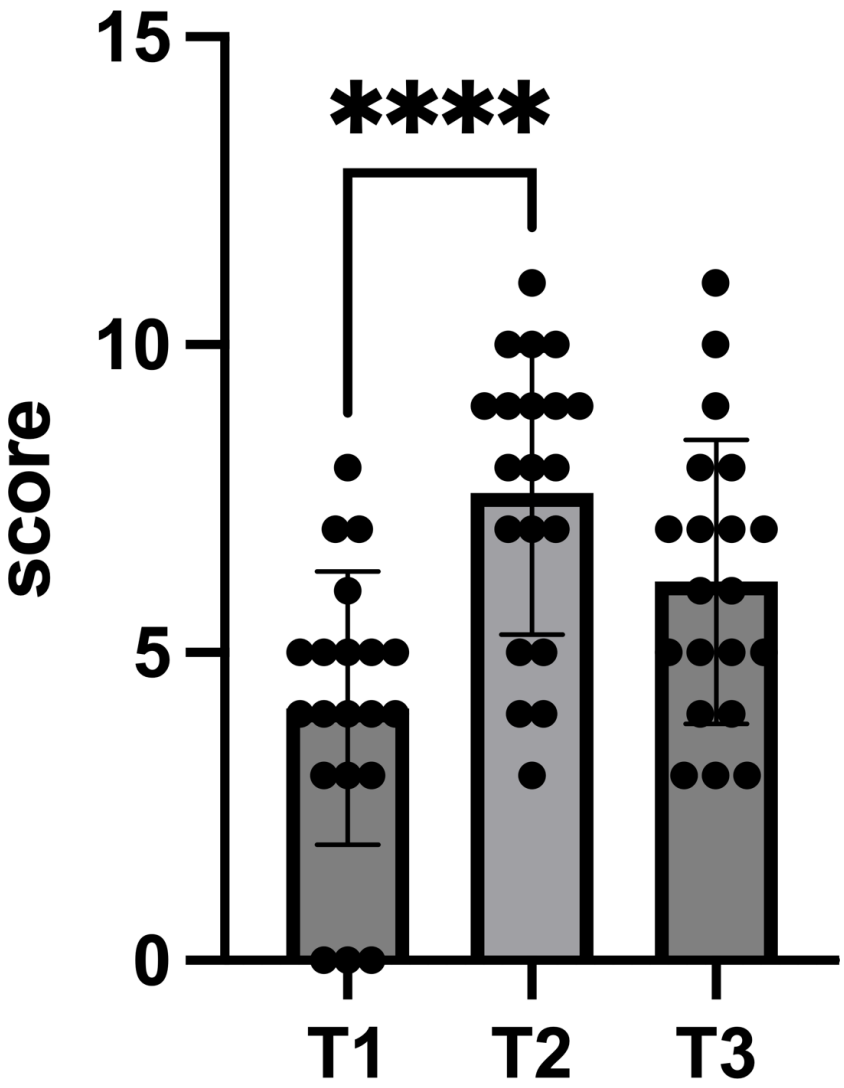

Figure 2 **The scores of professional knowledge tests before, in and after PCITs.**
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DISCUSSION

The study gives a longitudinal comparison between traditional PCIT and VR based PCIT in terms of changes in mastering professional knowledge of oral implantology and horizontal comparison of subjective feedback under different PCITs. Besides, student-teacher interactions and learning duration were recorded and summarized during both PCITs.

All subjects in the study are enrolled as postgraduate students in the School of Stomatology. Both groups received theory-based courses of oral implantology before training, but neither have practical basis for clinical implantation, unequipped with relevant implanting skills. VR based PCIT and traditional PCIT were both set up at the

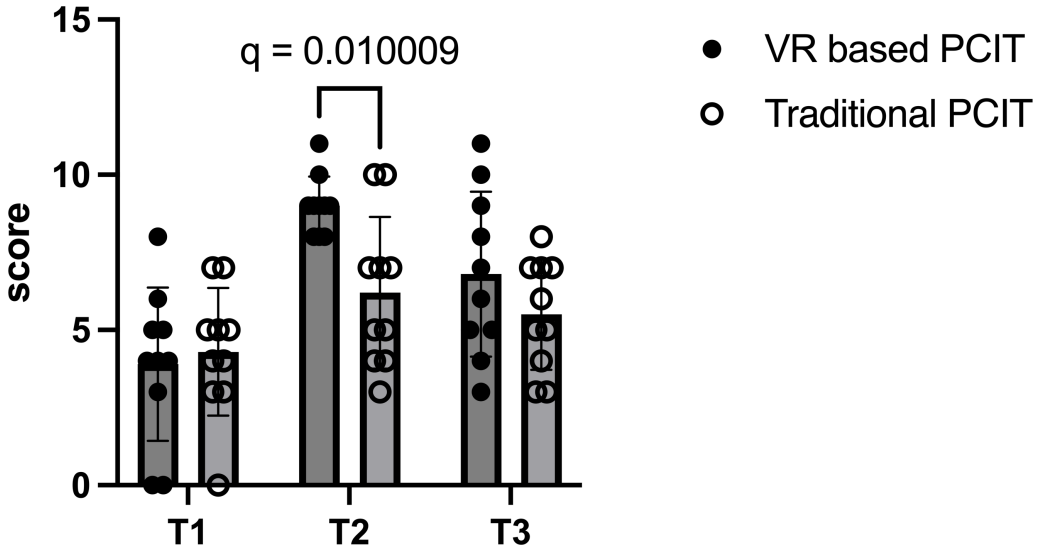

Figure 3 The scores of professional knowledge tests before, in and after separate PCIT groups.
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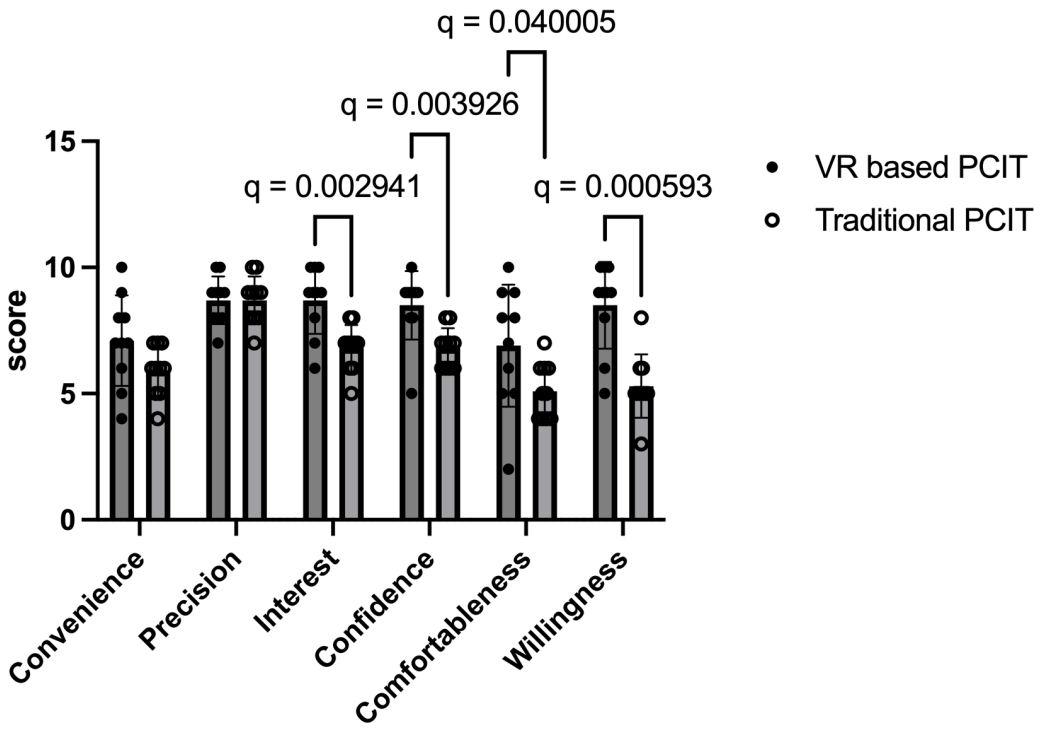

Figure 4 The scores of subjective evaluation test in separate PCIT groups.
Full-size DOI: 10.7717/peerj.18891/fig-4

Table 1 The items of subjective evaluation test and average score.

Items		Average score
Do you find easy to follow in corresponding PCITs? (Convenience) (Score: 1–10)	VR based PCIT	7.10
	Traditional PCIT	5.90
To what extent do you understand the basic operation of implantology? (Precision) (Score: 1–10)	VR based PCIT	8.70
	Traditional PCIT	8.70
Are you Interested in corresponding PCITs? (interest) (Score: 1–10)	VR based PCIT	8.70
	Traditional PCIT	6.80
Do you feel confident in learning implantology after corresponding PCITs? (Confidence) (Score: 1–10)	VR based PCIT	8.50
	Traditional PCIT	6.80
Do you feel comfortable during corresponding PCITs? (Comfort) (Score: 1–10)	VR based PCIT	6.90
	Traditional PCIT	5.10
Are you willing to experience corresponding PCITs again? (Willingness) (Score: 1–10)	VR based PCIT	8.50
	Traditional PCIT	5.30

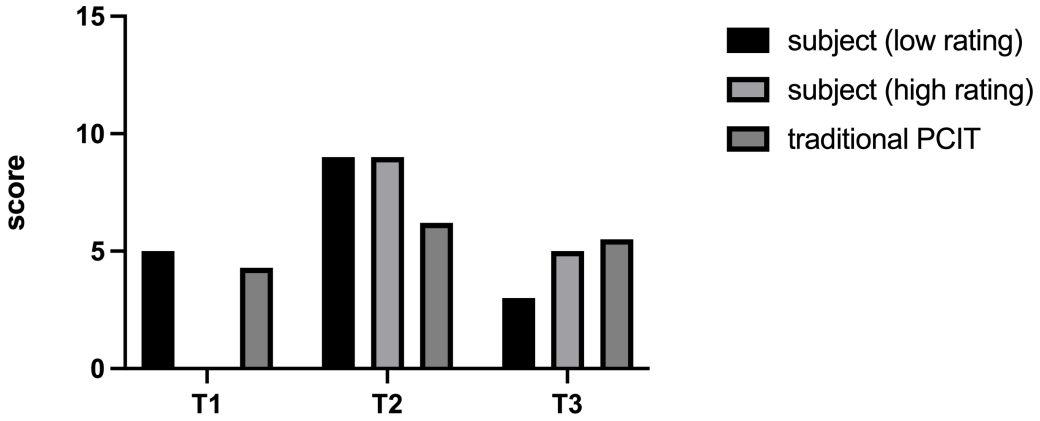

Figure 5 The scores of professional knowledge tests in specific PCIT target.
Full-size DOI: 10.7717/peerj.18891/fig-5

Ran Jiaba campus in the School of Stomatology, where all subjects are continuing their postgraduate program. And the sample retention rate reaches 100% as for both groups.

With the help of specific calculation logic and the VR system of computer science, VR-based PCIT simulates highly realistic patient models with different disease statuses, overcoming the limitations of previous training modes (*Ochandiano et al., 2022*), including the restricted number and types of patients. *Via* uniDent simulator, students can choose different dentition defect types and patient models with or without systematic disease, including diabetes, hypertension, *etc.*, and enhance corresponding implanting skills according to specific clinical scenarios (*Plessas, 2017*). For example, in the case of upper molar loss, VR based PCIT mainly focuses on the study of the sinus floor anatomy and sinus ridge distance, thus providing an appropriate guidance on maxillary sinus floor lifting arrangement. However, it puts emphasis on the assessment of inferior alveolar nerve in the case of lower molar loss to avoid unnecessary injury. Apart from repetitive personalized

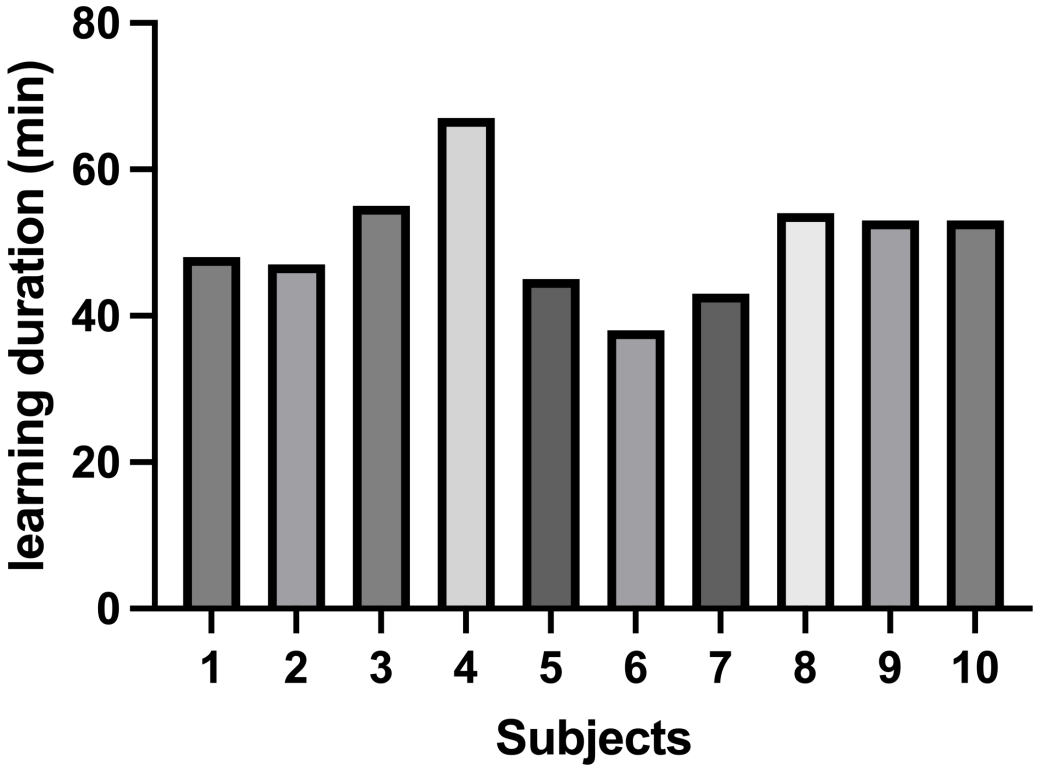

Figure 6 The scores of professional knowledge tests before, in and after PCITs.
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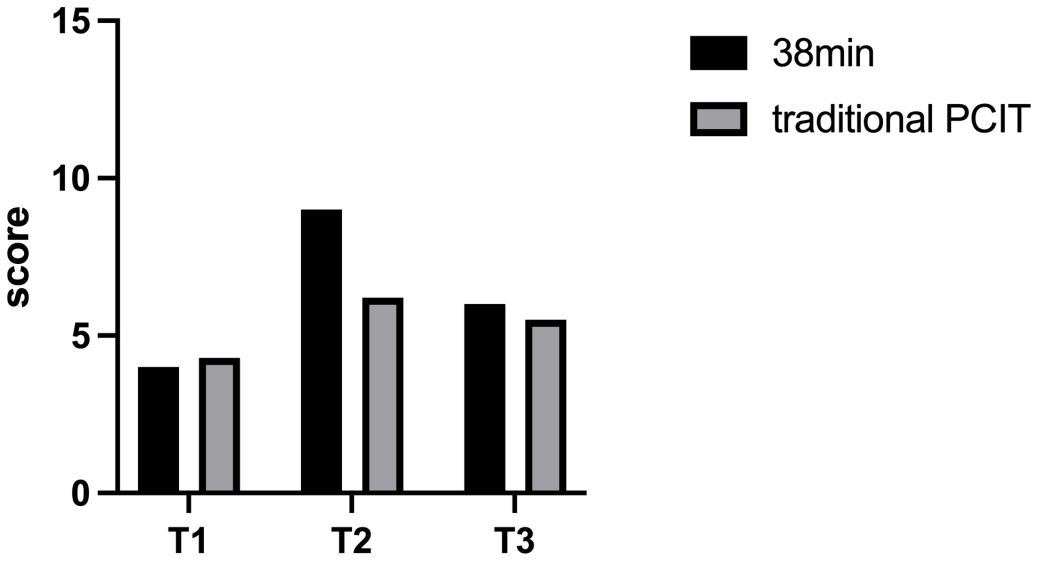

Figure 7 The scores of professional knowledge tests in specific PCITs target.
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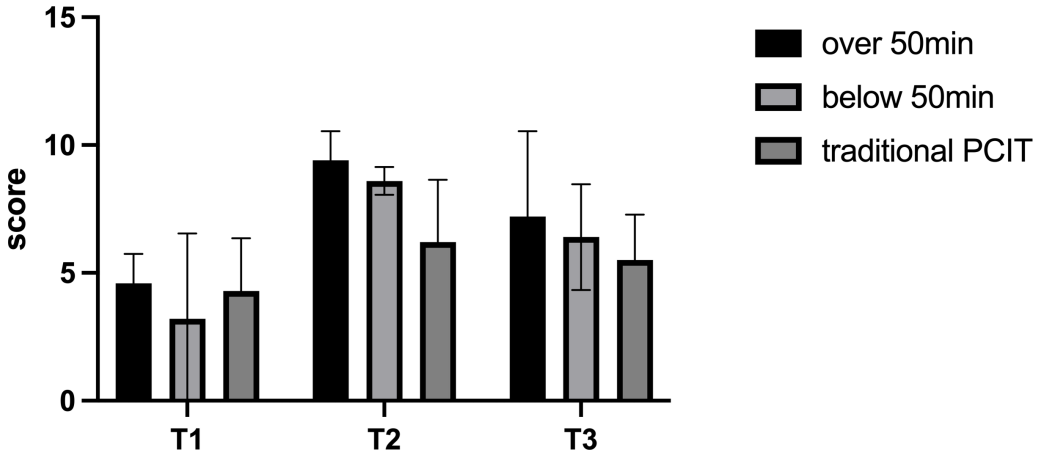

Figure 8 **The scores of professional knowledge tests in specific PCITs target.**
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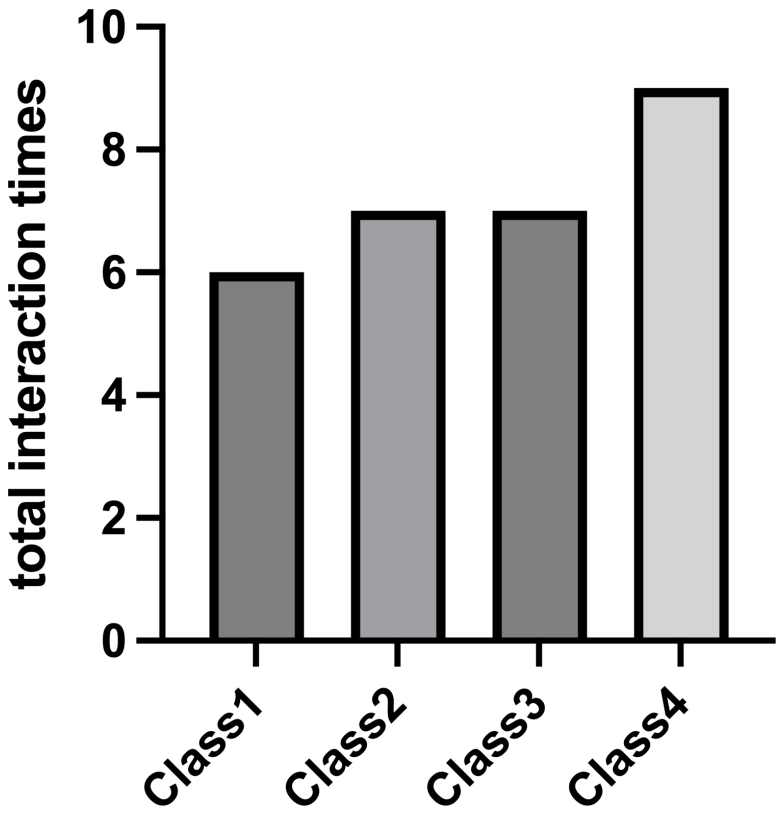

Figure 9 **Recording of teacher-student interaction times in traditional PCIT.**
Full-size DOI: 10.7717/peerj.18891/fig-9

training, VR based PCIT offers fine supervision on the training process. When mistakes occur, such as false locating and injuries of other teeth, VR system will provide instant notes and support for students.

T-1, T-2 and T-3 analysis

Three professional tests were given to subjects before (T-1), in (T-2) and after (T-3) PCITs so as to analyze the mastery of professional knowledge and knowledge retention. Tests have covered clinical and theoretical information related to oral implantology, including implanting system, oral anatomy, clinical techniques of implantation and key steps, *etc.*

The data shows that after PCITs, the knowledge mastered of both groups increased significantly from T-1 to T-2 ($P < 0.05$), among which, score of T-2 in VR based PCIT is significantly higher than that in the traditional PCIT. One highly possible reason is that VR based PCIT functions as a more individaul and user-friendly training method, which helps to consolidate theories related, while facilitating the operation under different circumstances (*Morales-Vadillo et al., 2019*).

Four weeks after PCITs, scores of both groups see a certain decrease. This is possibly because after PCITs, neither groups have participated in other relevant learning. In this case, the results of T2s and T3s are in consistency with the Ebbinghaus's forgetting curve (*Murre & Dros, 2015*). But compared with traditional PCIT, subjects in VR based PCIT achieved significantly higher scores in T-3, which could be due to a highly simulated visual, auditory and tactile experience. As scholars put it, during the teaching process, students behaved better in memorizing under multiple sensory stimulus. Compared with mechanical memory, correct sensory feedback contributes positively to a precise mentality formation, helps to derive the context of knowledge and build effective recalling and recognition (*Iqbal et al., 2022*). Unlike traditional PCIT, which lies in the information of texts, pictures and videos, VR based PCIT utilizes three-dimensional modeling and provides a straightforward access to the oral cavity. From gingiva to alveolar bone, frenum linguae to tubera maxillare, every anatomical structure can be illustrated in the three-dimensional and dynamic manner. Students can observe from different visual sights by moving angles. Besides, during interactions, VR based PCIT, equipped with precise tactile technology, provides students with original sense of control, which serves to build solid muscle memory, a rather fundamental and necessary element for surgical training.

Subjective evaluation test analysis

Scoring in SET shows that students are more inclined to VR based PCIT. The same scoring level in "Precision" illustrates that VR based PCIT is equipped with competitive capability of imparting knowledge compared with traditional PCIT. While in the other items, including the "Convenience", "Interest", "Confidence", "Comfort", and "Subjective initiative", scores of VR based PCIT were higher than the ones of traditional PCIT.

In the reference of scoring in the traditional PCIT, items of "Convenience", "Comfort" and "Willingness" received relatively low points, which possibly indicates the anticipation of students to have access to an innovative approach of learning. As for "Convenience" subjects in traditional PCIT find it not easy to follow during instructions, which implies the difficulty of finding a fine balance between "slow learners" and "fast learners". The relatively low score in "Comfort" indicates barriers subjects might encounter and the lack of immediate solutions. Having been cultivated in a traditional education setting, subjects

may have become used to the unchanged mode and expect new ''stimuli'' to bring back their willingness.

Different from traditional PCIT, VR based PCIT offers more flexibility in time schedule and possibilities of teacher-free interactions, which facilitates the arrangement of courses. From the result of high rating subjects, we are able to witness how VR based PCIT cultivates learners, encourages learning and improves knowledge mastery. This is possibly because VR based PCIT fully takes individual learning features into consideration, where slow-paced students have chances to take time on difficult portions in practice, meanwhile, fast-paced students are able to further their study into the next chapter. Besides, the immersive class environment cultivated by VR technology facilitates studying in a concrete, vivid and interesting way. In addition, apart from the realistic feelings, students can explore the anatomical structure of oral and maxillofacial region according to their own will, and improve their confidence without worrying about failure. In this case, positive feedback tends to encourage students to absorb fresh knowledge and improve their learning efficiency (*Khattak et al., 2022*).

However, the item of ''Comfort'' also rates in a relatively lower point than the others in VR based PCIT. This might mean a possible optimization in VR based PCIT when subjects have difficulties while learning. Although, the uniDent simulator applied in the VR based PCIT group is able to support with instant instructions when problems emerge and allows repetition, the solutions are relatively patterned and originated from published volumes. Under these circumstances, some may anticipate a more reader-friendly version for instruction or reminders, which traditional PCIT might be able to provide for convenience.

Specific situation analysis of teaching activities

During traditional PCIT, time is wasted on tool distribution, head mold installation, and answering questions. On the contrary, there is no need for complicated preparation in VR based PCIT and instant feedback can be achieved for questioning, which shortens the waiting span and enables a more efficient study accomplishment. Moreover, based on the results of learning duration in VR based PCIT, the learning span does not have obvious influence on the final tests and compared with traditional PCIT, immediately after the PCIT, VR based PCIT shows a better test performance.

Additionally, according to the recording of teacher-student interactions, average time per class is only 7.25 min, indicating the insufficient interactions per student, which could be explained by the limited number of teachers. Under this circumstance, it is more likely for students to operate incorrectly without professional support. However, compared with traditional PCIT, VR based PCIT realizes the one-on-one interaction, because students are able to turn to instant feedback or instructions by the uniDent simulator during any time point of the process, and choose to continue or repeat, thus solving the problems of facilities, slow feedback and restricted training opportunities. In this case, students are free to allocate their own training, and obtain instant support when making mistakes, insuring the validity of their study.

VR based PCIT application possibilities

According to the research data analysis, the PCIT contribution of the VR technology might be positive.

Owing to the improved professional knowledge mastery, a possible application in students, learning routine might enhance the ability of them obtaining a basic understanding of oral implantology in both theoretical and clinical manner.

Based on the SET analysis results, we assume a higher anticipation towards VR based PCIT from students when they start as freshmen, in which case, a head start program using VR based PCIT may increase the probability of sustainable learning in the long run.

Compared with traditional PCIT, VR based PCIT sees a more flexible learning expectancy and hopefully provides extracurricular parctices for students in need. Setting up classrooms specifically for VR based PCIT not only alleviates loads from the faculty, but enables students to focus more on problem-based learning simultaneously.

LIMITATIONS

As the results show, VR based PCIT enables students to improve their professional knowledge in a more efficient and effective way gaining greater popularity compared to traditional PCIT.

In terms of the study design, however, owing to the necessity of increasing sample size and follow-up studies, the massive and all-rounded application to the dental implanting learners are intended to meet the requirement of long-term assessment and generalization in the current education manner. In this case, a class-based intervention is hopefully conducted in a comparable group learning mode as traditional PCIT does. Meanwhile, due to the need of identity to fully simulate college class routines, a detailed VR based PCIT class schedule is supposed to be designed within a semester.

Besides, during enrollment, both groups had learned theories of oral implantology in their undergraduate program. Therefore, we are not entirely sure about the influence of VR-based PCIT alone on new learners. In this case, the learning conditions of the subjects are supposed to be taken into consideration during selection. Additionally, broader types of subjects ranging from beginner to skilled dentists contribute positively to a well-rounded assessment of the application in various scenarios.

Simultaneously, we analyzed the independent application of each PCIT, but the combination between traditional and VR based PCIT serves to help construct a more precise understanding of the function VR based PCIT is equipped with in following education mode. A new blended training method will be explored in the following study.

Moreover, taken the targeted population as one of the influencing factors, the origin of samples is restricted to Chinese, from whom a possible cultural penetration, language identity, learning habits and so on might cause impact on the various data collected. In this case, we look forward to collecting data on more cosmopolitan approaches.

CONCLUSIONS

Compared with traditional PCIT, VR based PCIT serves better in enhancing students' knowledge mastery following the PCIT, and achieves higher overall maintaining levels in 4 weeks. Meanwhile, VR-based PCIT generally receives higher rating scores in multiple subjective feedback categories, indicating a stronger preference among subjects. During VR based PCIT, students can not only arrange their time schedule individually, but fully simulate clinical surgeries through one-on-one interactions with VR systems simultaneously. Although VR based PCIT illustrates promising applicable possibilities in students' learning method, we still see several limitations remaining to be solved, including the restricted sample size, long-term assessment data, massive and regular application among students, *etc.* In conclusion, VR technology creates a brand-new possibility for PCIT, which could excavate a new direction in term of students' daily training items in the future.

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ADDITIONAL INFORMATION AND DECLARATIONS

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Competing Interests

The authors declare there are no competing interests.

Author Contributions

- Yangjie Li performed the experiments, analyzed the data, prepared figures and/or tables, and approved the final draft.

- Xu Chen performed the experiments, analyzed the data, prepared figures and/or tables, and approved the final draft.
- Yuan ding Huang performed the experiments, authored or reviewed drafts of the article, and approved the final draft.
- Qingqing He performed the experiments, authored or reviewed drafts of the article, and approved the final draft.
- Dize Li performed the experiments, authored or reviewed drafts of the article, and approved the final draft.
- Shanshan Hu performed the experiments, authored or reviewed drafts of the article, and approved the final draft.
- Peng Xu performed the experiments, authored or reviewed drafts of the article, and approved the final draft.
- Tao Chen conceived and designed the experiments, authored or reviewed drafts of the article, and approved the final draft.
- Xiongwen Ran conceived and designed the experiments, authored or reviewed drafts of the article, and approved the final draft.

Human Ethics

The following information was supplied relating to ethical approvals (*i.e.*, approving body and any reference numbers):

The Stomatological Hospital of Chongqing Medical University granted Ethical approval to carry out the study within its facilities (Ethical Application Ref: 2024-026).

Data Availability

The following information was supplied regarding data availability:

The raw data are available in the Supplementary Files.

Supplemental Information

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