Virtual Simulation Software for Oral Histopathology to Assist Dental Students in Making Tooth Ground Sections and Enhancing Knowledge of Dental Hard Tissues

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Objective: *To evaluate the effects of a novel software developed to assist dental students in making tooth ground sections and gaining knowledge of dental hard tissues.*

Methods: *Students were divided into three groups (class-use group, after-class-use group and control group) and taught how to make real sections or allowed to use the aforementioned software to make virtual tooth ground sections on the computer. The present authors then assessed the efficiency of making the first tooth ground sections, the quality of ground sections and performance skills.*

Results: *The sectioning time for the class-use group was less than that for the after-class-use group and control group (P = 0.027), and the quality of sections for the class-use group was higher (P = 0.036). In the objective test 1 week later, the after-class-use group performed better than the control group (P = 0.019). Users agreed that the software stimulated their interest and improved their learning results.*

Conclusion: *This software is an efficient tool to help students to make tooth ground sections and study the histology of dental hard tissues in a simple and functional way.*

Keywords: *dental hard tissue, oral histopathology, tooth ground sections, virtual software*

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Teeth consist of enamel, dentine, cementum and dental pulp, which attach them to bones by way of dental-supporting connective tissues.[1] Enamel, dentin and cementum are included among the dental hard tissues.[2] The conventional methods used to learn the structure of hard tissue are decalcifying or grinding into thin sections.[3,4] The hard tissues of teeth are highly mineralised, especially enamel, which contains more than 96% inorganic material.[5] The enamel cannot be observed after demineralising, although parts of the dentine structure remain.[6-9]

Since sufficient space and material are required to make tooth ground sections, it is difficult to carry out this experiment in all universities. To solve the problem, the present authors' team developed a novel cutting machine to make tooth ground sections.[10] On this basis, they developed a software that simulates the entire process of making tooth ground sections. In this software, users can simulate the whole process of making tooth ground sections, then use the novel cutting machine to make the real tooth ground sections by themselves, and finally observe the tooth ground sections under the microscope.

The aim of this article is to assess the effect of the virtual simulation software to demonstrate that it can help students make better-quality tooth ground sec-

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tions efficiently; to determine that it can assist dental students in learning the structure of dental hard tissues; and to investigate students' attitude towards the software.

Materials and methods

A randomised controlled trial was conducted with three groups: the control group, class-use group and after-class-use group. In the first phase, all participants completed the process of making tooth ground sections during the first oral histopathology experiment class. The difference between the groups was as follows: the control group did not use the ground sections teaching software in the first phase, the class-use group used the software only during the class, and the after-class-use group used the software only after the class. An objective test about the knowledge of dental hard tissues was performed after 1 week. In the second phase, all participants were given access to the software and were able to use it freely, then user satisfaction questionnaires regarding the use of the virtual simulation software were collected at the end of the semester. The Medical Ethics Committee of Hospital of Stomatology, Sun Yat-sen University approved the trial on 3 August 2021(KQEC-2021-51-01).

Participants

The present authors recruited volunteer participants from third-year undergraduates who were studying the oral histopathology curriculum at Guanghua School of Stomatology, Sun Yat-sen University. There was no significant difference in the participants' college entrance examination scores, and none of them had engaged in any systematic learning about the histology of teeth or made tooth ground sections before. To be included, students needed to be third-year undergraduates majoring in stomatology, whereas students who had studied the histology of teeth systematically or made tooth ground sections before were excluded. Participants withdrew from the study if they decide to exit. All participants were informed of the purpose and duration of the study. Overall, 110 students took part in this study (41 men and 69 women).

Instruments

Oral histopathology simulation software

A multidisciplinary team of pathologists, dental students and engineers developed a novel software (China Computer software copyright registration certificate no. 2019SR015666, no. 2020SR0237882) that can simulate the whole process of making tooth ground sections, including tooth embedding, cutting, grinding, dehydrating and sealing (Supplementary MP4 file, provided on request). The software was pilot tested by fourth-year undergraduates majoring in stomatology at Sun Yat-sen University (n = 103). To ensure the quality of the software, the feedback forms and recommendations from the pilot data were collected to improve the software.

Assessments, objective test results and predictions

The software was assessed using four indicators, namely the efficiency of making 50-μm tooth ground sections first, the quality of tooth ground sections, the students' scores for the objective test about dental hard tissues, and user recognition. The time it took for participants to achieve the first successful 50-μm ground sections from the embedded teeth was recorded to evaluate the efficiency. The quality of the ground section was scored by two independent observers for various features under a light microscope. Based on the required standards of completeness and clarity, the ground sections were classified as either qualified or unqualified. If a section was deemed unqualified and thus unsuitable for observation, students could use the digital slides as an alternative for observation. The scoring criteria were as follows:

- Qualified: Tooth ground sections that are unbroken and distinguishable and where it is easy to observe the structures like enamel rod, enamel spindle, enamel tuft, enamel lamellae, dentinal tubule and Tomes granular layer.
- Unqualified: Tooth ground sections that are broken or indistinguishable, or that make it difficult to observe the structure of dental hard tissues.

The objective test and questionnaires were designed to assess participants' knowledge of the dental tissues and attitude towards the software after making the tooth ground sections. The objective test consisted of a total of 21 multiple-choice questions, with one point awarded for each (Supplementary file 2, provided on request). There were five answer options to select: 1 (totally disagree), 2 (disagree), 3 (unsure), 4 (agree) and 5 (totally agree). To analyse the correlation between users' usage and recognition of the software, data concerning their frequency and duration of use were also collected and graded as 1 (< one time), 2 (one time), 3 (two to three times), 4 (four to five times) and 5 (> 5 times) for fre-

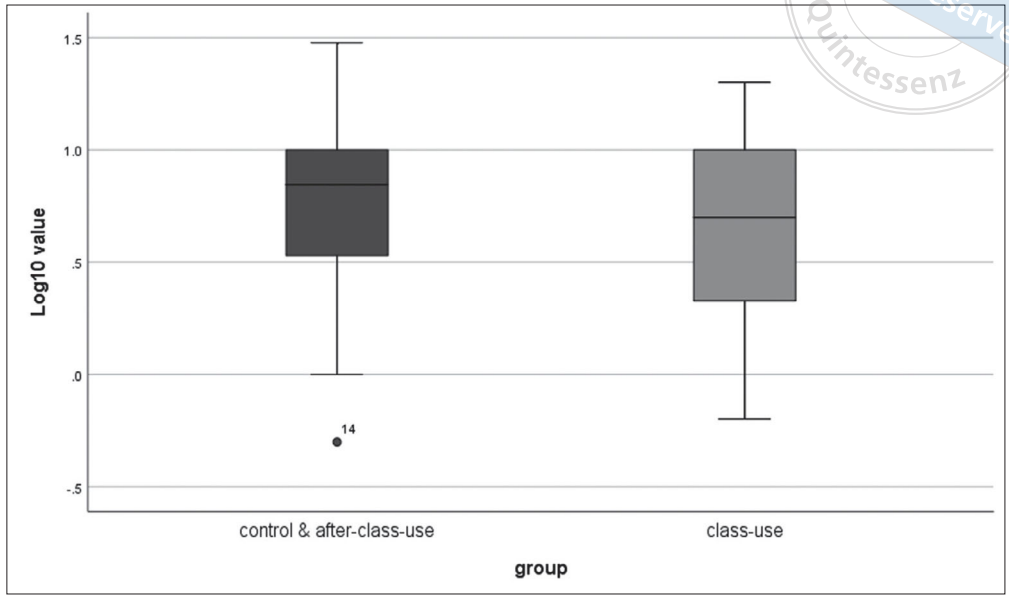

Fig 1 The sectioning time for the class-use group was shorter than that for the control group and after-class-use group.

quency, and as 1 (< 5 minutes), 2 (5 to 10 minutes), 3 (10 to 30 minutes), 4 (30 to 60 minutes) and 5 (> 60 minutes).

Interventions

Students in the class-use group took traditional lessons, which consisted of lectures, slides and video content, and used the virtual simulation software for oral histopathology in class. Students in the after-class-use group took traditional lessons in class and used the virtual simulation software for oral histopathology after the first class. Students in the control group, meanwhile, took traditional lessons and did not use the virtual simulation software.

Statistical analysis

All statistical analyses were performed using SPSS Statistics version 25 (IBM, Armonk, NY, USA). Outliers were eliminated and normality tests were performed on all data. The tooth ground sections were first prepared to a specific thickness, such as 50 μm, before proceeding to the next step in the process. A chi-square test was used to analyse the characters of tooth ground sections and compare whether there was any difference in the qualified rate of tooth ground sections between the class-use group and the combined group. Scores were collected from the objective test relating to dental hard tissue knowledge taken by the class-use group, control group and after-class-use group 1 week after the class. The test scores were then analysed using a Mann-Whitney rank sum test for non-normal distribution to determine whether there were performance differences among the three groups. Pearson correlation analysis was used to analyse the relationship between users' interest in the software and their agreement on its effect.

Results

A total of 110 students were enrolled at beginning of the study, 108 of whom completed it and 2 of whom dropped out.

Efficiency of making tooth ground sections first

A total of 104 valid records were collected because four students did not finish the sectioning on time (within 30 minutes). The result of a two independent samples *t* test indicated that the sectioning time of the class-use group was significantly shorter than that for the combined group ($P = 0.027$); in other words, using the software in class can improve students' efficiency at making 50-μm tooth ground sections first (Fig 1). The time taken by participants to achieve their first successful 50-μm ground sections of class-use group (n = 50) was 6.438 ± 0.806 minutes in the class-use group, and that of the combined group (n = 54) was 8.757 ± 1.030 minutes. After Lg10 conversion, the data were normally distributed.

Quality of tooth ground sections

The result of the Chi-square test revealed that the quality of tooth ground sections in the class-use group was better than the combined group ($P = 0.036$). Two independ-

Table 1 The quality of tooth ground sections was better in the class-use group than in the control and after-class-use group

Group	Quality		Sum	Pass rate
	Unqualified	**Qualified**		
Class-use	5	45	50	90.00%
Control and after-class-use	14	40	54	74.07%
Sum	19	85	104	81.73%

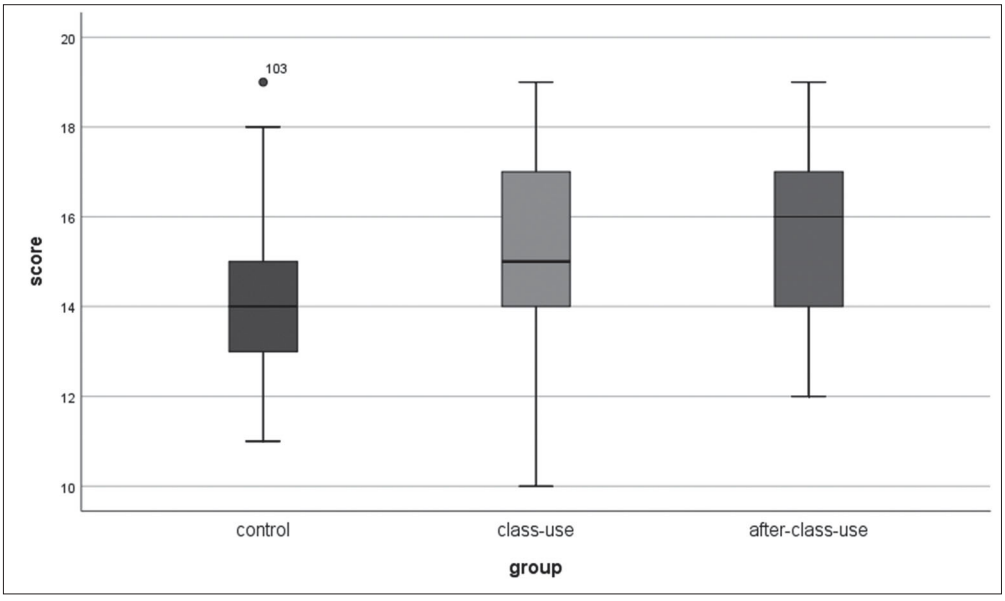

Fig 2 The mean score for the after-class-use group was higher than that for the control group and class-use group.

ent observers graded 104 pieces of tooth ground sections according to the criteria mentioned above. In the class-use group, five pieces were unqualified and 45 pieces were qualified according to the scoring criteria. However, in the control group and after-class-use group, 14 pieces were unqualified and 40 were qualified (Table 1).

Objective test

A total of 108 participants completed the objective test. The test scores of the three groups were compared. The after-class-use group had a better effect than the class-use group and control group. The results indicated that using the software independently after class can have a better effect on helping users to master knowledge about dental hard tissues than use in class (Fig 2). The mean score for the after-class-use group (n = 24) was 15.750 ± 0.427, and that for the class-use group (n = 53) was 15.075 ± 0.285, control group (n = 31) was 14.419 ± 0.337. The result of the rank sum test showed that the mean score of the after-class-use group was higher than that of the control group ($P = 0.019$). The mean score of the class-use group was higher than that of the control group, whereas there was no significant difference between the control group and the class-use group.

Satisfaction questionnaire

A total of 93 valid questionnaires were collected. The results showed that the mean score for all the items was higher than 3 points, indicating that the students thought the software could improve their interest and the effect on their learning (Table 2).

Then, the correlation between the mean score for usage and recognition was analysed. The results showed that usage is positively correlated with recognition of the software (Fig 3). When users used the software more frequently and spent more time on it, they recognised that it could improve their interest and learning effect more ($P = 0.044$, r = 0.209).

The questionnaire also contained an open-ended question that enabled users to make suggestions about the software. Some typical examples included adding audio explanations beside the subtitle; improving the quality (higher resolution) of the 3D display of the dental structure; adding a mobile or tablet version;

Table 2 Mean ± standard deviation (SD) for five items in the questionnaire

Question	Mean ± SD
1. Compared with traditional teaching, the virtual simulation software of oral histopathology stimulates my interest	4.000 ± 0.794
2. Compared with the traditional teaching, the virtual simulation software relating to oral histopathology can improve my efficiency when making tooth ground sections	3.796 ± 0.904
3. Compared with traditional teaching, the virtual simulation software relating to oral histopathology helps me become more familiar with the process of making tooth ground sections	4.151 ± 0.793
4. Compared with traditional teaching, the virtual simulation software relating to oral histopathology can improve my independent thinking ability	3.699 ± 0.930
5. Compared with traditional teaching, the virtual simulation software relating to oral histopathology can improve my understanding and mastery of knowledge about the structure of dental tissues	4.033 ± 0.896

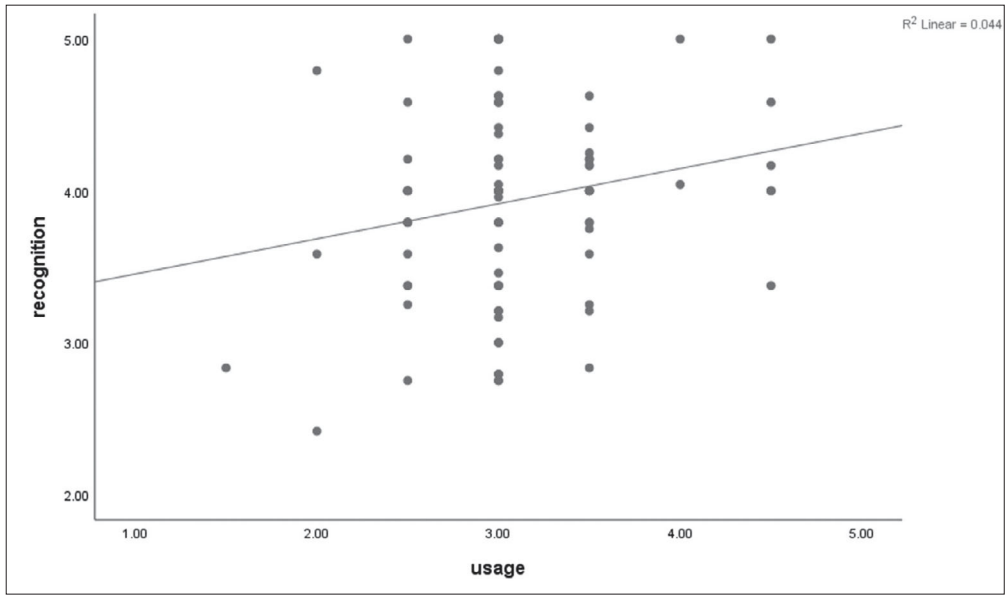

Fig 3 Usage is positively correlated with users' recognition of the software.

adding more slide images and examples; and adding a "Questions and Answers" column to help students to gain more experience.

Discussion

To the best of the present authors' knowledge, this is the first virtual software that allows dental students to simulate the entire process of making tooth ground sections and watch it on a computer. Making tooth ground sections is the only way for dental students to study dental hard tissues such as enamel, dentine and cementum under a microscope.[11] Since it requires sufficient space and equipment, such as cutting machines, stones for grinding and extraction of teeth, it is time-consuming and costly, so it is impossible to make tooth ground sections in a routine practical laboratory.[12] The present authors' software can assist dental colleges that do not have the necessary experimental facilities in conducting simulation experiments; all they need is a computer. The software can benefit more dental students without restrictions concerning time and conditions.

The present authors found that using their software in class can improve students' performance in making tooth ground sections. They can make the first 50-μm tooth ground sections more efficiently ($P = 0.027$) and in better quality ($P = 0.036$). Recently, 3D computer modelling and interactive virtual simulation have been widely applied in the teaching of medical disciplines.[13,14] The virtual software allows students to acquire knowledge more effectively and master the content in class.[15-17] For example, virtual implant planning software has a good effect on implant education by simplifying the learning process and improving outcomes.[15,16] Virtual reality simulators offer significant benefits in dental education, including improving dental preparation

skills, increasing learning efficiency, offering support for the adaptive learning progress, customising training content and boosting students' confidence through immediate feedback and quantitative assessment.[17,18] The software combines the theory learnt in the traditional course with the simulation process in the virtual software, enabling students to master the procedure on a deeper level and then make higher quality tooth ground sections more efficiently. It also provides an immersive learning environment that allows students to learn the process of making ground sections in advance, which has also been shown to strengthen their hands-on skills. As traditional teaching methods are being complemented by innovative strategies to adapt to the learning styles of a new generation of students, this novel software could be a successful supplement for traditional teaching.[19,20]

The present study found that the software can help dental students improve both their efficiency and quality of making ground sections using the traditional method, and their performance on an objective test. In the software, knowledge about dental hard tissues is displayed in the form of tips and users can review related knowledge while making ground sections. Because of the combination of practice and theory, students can study the dental hard tissues more effectively. The present authors also investigated whether using the software after class can provide a better learning effect for students, and found that students in the after-class-use group (who chose to use the software after class) performed significantly better in the objective test ($P = 0.019$). Their mean score was the highest among the three groups, which indicated that using the software actively can assist students in mastering knowledge about dental hard tissues compared with students in the class-use group. This may be because they have more time to study compared to the limited time in class, or because they can improve their self-studying ability by using the software.

The questionnaire revealed that users showed a great interest in the software. Most of them agreed that the software could not only help them make tooth ground sections and acquire knowledge, but also boost their ability to think independently. It is interesting to note that the more time they spent using the software, the more they agreed with this notion. The study indicates that the virtual simulation software of oral histopathology is a good supplement to learn about dental tissues.

Distance learning has grown rapidly in recent years.[21,22] Thus, this software can also be an invaluable aid to teachers providing dental education, especially for students who lack good teaching resources.

Although the present results are encouraging, some shortcomings remain. Some details of the software can be improved, such as the audio explanation, scenes, slide images and modules. In addition, the software could be presented to students more conveniently and share more professional knowledge of oral histopathology. Thus, the present authors tried to upgrade the software by adding more features. After the upgrade, the software now contains more content related to oral histopathology and has been uploaded to the campus network for students to use (https://course.sysu.edu.cn/kouqiang/index.html).

Conclusion

The present study demonstrates that virtual software significantly improves the learning efficiency and skills of dental students, promotes their self-directed learning and repeated practice and enhances their confidence. Students who used the software after class performed better in the test, indicating the software's positive impact on learning outcomes. Furthermore, the software provides an immersive learning environment and immediate feedback, serving as an effective supplement to remote learning.

Conflicts of interest

The authors declare no conflicts of interest related to this study.

Author contribution

Drs Zhuo LIN, Yi Cheng HONG, Yun Yi HUANG contributed to the formal analysis, data curation and manuscript draft; Drs Xuan Yi CHEN, Zhi Pei CHEN, Yi Jiao LI, Xue Cong LI contributed to the conceptualisation, validation, software and methodology; Drs Xiao Hua CHEN, Meng XU contributed to the supervision, project administration and manuscript revision.

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