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3D reconstructed models based on real cervical cancer cases for undergraduate gynecological oncology education: a pre- and post-test study

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Abstract

Background The landscape of medical education is rapidly evolving, driven by advancements in technology. This evolution has ushered in a new era characterized by digitization, connectivity, and intelligence. In this era, traditional teaching methods are being augmented with innovative technologies such as virtual learning, artificial intelligence platforms, and access to cloud-based health platforms. One notable advancement is the integration of three-dimensional (3D) reconstructed models into medical education, particularly in fields like gynecological oncology.

Methods This study introduces 3D reconstructed models based on real cervical cancer cases as a teaching tool for undergraduate gynecological oncology education. Participants were fourth-year Clinical Medicine students of Wuhan University, China. Using student identity document numbers for grouping, half were assigned to the control group (odd numbers) and the other half to the 3D reconstructed model teaching group (even numbers). All the students completed the pre-tests before receiving traditional teaching on cervical intraepithelial lesions and cervical cancer. The control group completed the post-tests after traditional teaching alone, while the 3D reconstructed model teaching group completed the post-tests after receiving the additional 3D reconstructed model teaching. Feedback on this innovative teaching tool was collected. The pre-tests and post-tests covered cervical intraepithelial lesions, cervical cancer and staging system, and female pelvic anatomy.

Results This study includes 267 students, with 134 in the control group and 133 in the 3D reconstructed model teaching group. The pre-test scores of the three tests between the control group and the 3D reconstructed model teaching group showed no statistical difference ($p > 0.05$). Compared to the control group, the post-test scores of the 3D reconstructed model teaching group in theoretical knowledge of cervical intraepithelial lesions and cervical cancer, female pelvic anatomy and 2018 International Federation of Gynecology and Obstetrics staging system for cervical cancer increased significantly ($p < 0.05$). Feedback from students underscored the visual benefits and engaging nature of the models, with many expressing that the 3D models provided a clearer representation of cervical cancer and enhanced their learning experience.

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Conclusion The integration of 3D reconstructed models into medical education represents a promising approach to address the complexities of teaching intricate subjects in anatomy such as gynecological oncology. These models offer a more intuitive and thorough visualization of anatomical structures and pathological processes, fostering a hands-on and exploratory learning experience for students.

Keywords Gynecological oncology, Cervical cancer, 3D reconstruction, Female pelvic anatomy, Medical education

Background

The rapid development of advanced technology propels the transformation of medical education into a new era [1]. The new era of medical education is characterized by digitization, network and intelligence. At present, courses in more and more medical disciplines combine traditional teaching methods with advanced technology, such as virtual learning [2], free access to cloud-based health platforms [3], learning on the go [4] and so on. It is a teaching practice to adapt to the new era of medical education to integrate the emerging advanced technologies into the medical courses continuously. Therefore, student-driven learning behaviors are gradually increasing [5].

In this new era of medical education, various advanced technologies are widely applied. This shift towards a more technologically integrated approach to medical education addresses the inherent challenges in teaching complex subjects. The appreciation of 3D concepts is one of the most demanding areas for medical student learning of anatomy. The 3D reconstructed models can depict anatomical structures, offering a multifaceted display of the human anatomy. Especially in the case of the complex anatomical variations and lesions, the 3D technology can enable detailed analysis and precise measurement by scanning and reconstructing targeted body regions. The application of these innovative tools, especially in understanding intricate anatomical structures, greatly benefits the educational process and student comprehension. Therefore, we considered incorporating 3D technology into the teaching process of gynecological oncology.

The female reproductive system is located in the center of the pelvic cavity, flanked by two major urinary and digestive system organs in close proximity, and surrounded by blood vessels, nerves and lymphatic system, creating a complicated anatomical relationship. The traditional way of relying on two-dimensional pictures only offers a single perspective to explain the anatomical structure of the female pelvis [6]. As a result, students often struggle to comprehend the anatomy of the female reproductive system.

Furthermore, gynecological tumors are even more complex. The staging of gynecological tumors is different based on factors such as size, location and other characteristics. For instance, cervical cancer has a complex International Federation of Gynecology and Obstetrics (FIGO) staging system [7], which further complicates the comprehension of such tumors.

In previous clinical research, we uncovered a significant correlation between the cervical tumor volume and adverse pathological factors [8]. Furthermore, we discovered that 3D reconstruction technology provides a more precise method for assessing tumor size, and we successfully utilized these models for more accurate staging of cervical cancer and predicting high-risk patients, making it highly potential for application in clinical diagnosis and treatment [9]. In the aforementioned study, 3D reconstructed models can display the location, extent, and relationship with surrounding tissues of the lesion more intuitively, which can assist clinicians in diagnosis and treatment. This led us to consider that 3D reconstructed models can also serve as learning materials for students. Through these models, students can understand anatomical structures and pathological changes more clearly, so we applied 3D reconstructed models in the teaching of gynecological oncology. For the current study, we constructed 3D reconstructed models for cervical cancer patients. With the aid of the accompanying visualization software, these models can mark various anatomical structures with different colors and allow for enlargement, rotation, and dissection, presenting the structure of the female reproductive system from various angles and planes. We hypothesize that the utilization of these 3D reconstructed models can enhance medical students' comprehension of the location, size, and extent of gynecological tumor lesions. Ultimately, this will aid in their understanding of how these lesions give rise to specific clinical symptoms and the corresponding therapeutic strategies. Therefore, we design the present study to investigate the following questions:

1. Can the incorporation of 3D reconstructed models into traditional teaching methods promote students' learning efficiency in gynecological oncology?
2. What are the undergraduates' feedback on the 3D reconstructed models designed for their gynecologic oncology teaching?

Methods

Participants

The participants of this study were students majoring in Clinical Medicine, Grade of 2020, from Wuhan

University, China. The participants were in their fourth year and in the same class. All the participants were enrolled in the study after an informed consent process.

Build 3D reconstructed models

In our previous study, the pre-treatment magnetic resonance imaging data from 54 patients with cervical cancer have been used to construct 3D reconstructed models of individual patients [9]. Organs were segmented from the DICOMs using a semi-automatic method. First, the DICOM data were imported into the Vitaworks platform. The platform automatically traced organs based on gray-level differences to segment them, creating distinct models for each organ. These models were then manually verified for accuracy, with refinements made as needed to improve precision. During this process, each organ model was assigned a distinct color for easier identification. Finally, all the segmented and refined models were automatically combined to generate the final 3D reconstruction.

Four patients at different stages were selected (Table 1). For each 3D reconstructed model, pelvic anatomy, including pelvis, blood vessels, various organs, as well as the size and extent of invasion of cervical cancer tumors, can be clearly displayed by VitaWorks®, a medical 3D Visualization Analysis System (Fig. 1). VitaWorks® allows the users to quickly and easily perform a variety of operations on 3D reconstructed models, including omnidirectional rotation, stepless zooming, transparency adjustment, selective hiding or display, and more. VitaWorks® Technology Co., Ltd. (Shanghai, China) provided technical and software support for our previous and present study.

Procedures

At the beginning of the study, we introduced the participants to this study design (Fig. 2). The student identity document (ID) numbers range from 2020305232001 to 2020305232267. Students were assigned to the control group (odd numbers) and the 3D reconstructed model teaching group (even numbers) based on the last three digits of their student ID numbers. The student ID numbers of the 3D reconstructed model teaching group were 2020305232002, 2020305232004, 2020305232006, 2020305232008, 2020305232010, ……, and 2020305232266.

This study was a pre- and post-test study. Three sets of test questions were designed, which were related to the theoretical knowledge of cervical intraepithelial lesions and cervical cancer, female pelvic anatomy, and the 2018 FIGO staging system for cervical cancer [10], respectively. The pre-test and post-test questions are the same, with a total of 10 questions, each worth 10 point. Participating students scan the Quick Response (QR) code through their mobile phones to enter the online test questions, and after submitting the answers, the test system can automatically score (Supplementary Material 1).

Firstly, all students in this class were invited to take a pre-test of the theoretical knowledge of cervical intraepithelial lesions and cervical cancer. Additionally, students were given the option to select and complete a pre-test via QR code for either female pelvic anatomy or the 2018 FIGO staging system for cervical cancer.

Approximately 100 min of traditional learning about cervical intraepithelial neoplasia and cervical cancer was conducted. After that, the students in the control group was taken to the next-door classroom to complete the post-test in order to evaluate the teaching effect of the traditional teaching. The control group was invited to take the post-test on the theoretical knowledge of cervical intraepithelial lesions and cervical cancer, and the corresponding post-test they initially select on either female pelvic anatomy or the 2018 FIGO staging system for cervical cancer.

Then 3D reconstructed models of cervical cancer were shown to the students in the 3D reconstructed model teaching group, which lasts about 20 min. During the presentation of the 3D reconstructed models,

Table 1 Clinicopathological characteristics of the 4 cervical cancer patients used to create 3D reconstructed models

Case	Age (years)	Pathology	Dimension (mm) [a]	Volume (ml)[a]	Stage[b]	Involvement
1	30	adenocarcinoma	33.0	3.2	IB2	carcinoma strictly confined to the cervix, and carcinoma > 2 and ≤ 4 cm in greatest dimension
2	52	squamous cell carcinoma	48.5	20.2	IIB	parametrial involvement but not up to the pelvic wall
3	51	squamous cell carcinoma	63.2	33.0	IIIC1	carcinoma involved the upper two-thirds of the vagina and pelvic lymph nodes
4	73	squamous cell carcinoma	44.5	17.4	IVA	carcinoma involved the parametria, mucosa of the rectum, and pelvic lymph nodes

[a] Measured on 3D reconstructed models based on cervical cancer patients

[b] According to 2018 FIGO staging system for cervical cancer

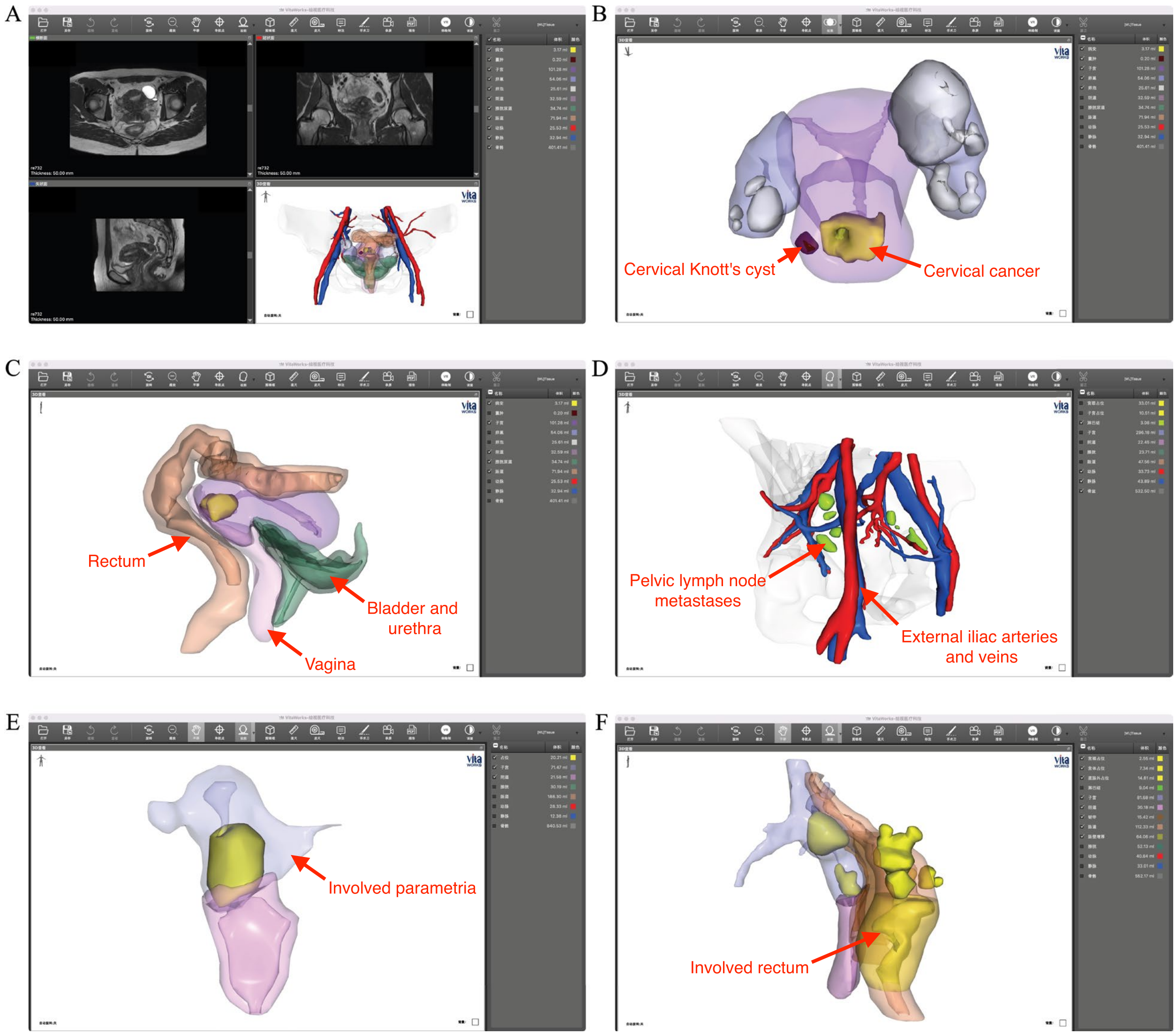

Fig. 1 VitaWorks® User Interface. **A** Initial working interface of Vitaworks®. **B** Simulate gynecological examination angles to demonstrate the uterus, bilateral ovaries, and cervical lesions. **C** Show the adjacent relationship between the rectum, uterus, vagina, bladder and urethra in the sagittal plane. **D** Display pelvic bony structures, blood vessels, and metastatic pelvic lymph nodes. **E** Show involved the parametria of cervical cancer in the coronal plane. **F** Show cervical cancer involvement extending to the rectum in the sagittal plane

the professor not only briefly summarized the content of traditional learning, but also included a review of the knowledge of female pelvic anatomy and the FIGO staging of cervical cancer. Finally, students operate VitaWorks® to inspect the 3D reconstructed models on their mobile terminals including phones and laptops for 10 min in class. After the traditional learning session and the exposure to the 3D reconstructed models of cervical cancer, a post-test was conducted to assess the impact of the intervention on the students' knowledge retention and comprehension. Similarly, the 3D reconstructed model teaching group were invited to participate in the post-test.

Finally, feedback from the 3D reconstructed model teaching group was also collected to gain insights into their perceptions of the effectiveness of the 3D reconstructed models based on real cervical cancer cases in enhancing their understanding of gynecological oncology. Among the students in the 3D reconstructed model teaching group, the students whose last three digits of their student ID numbers are 020, 040, 060, 080, 100, 120, 140, 160, 180, 200, 220, 240, and 260 will

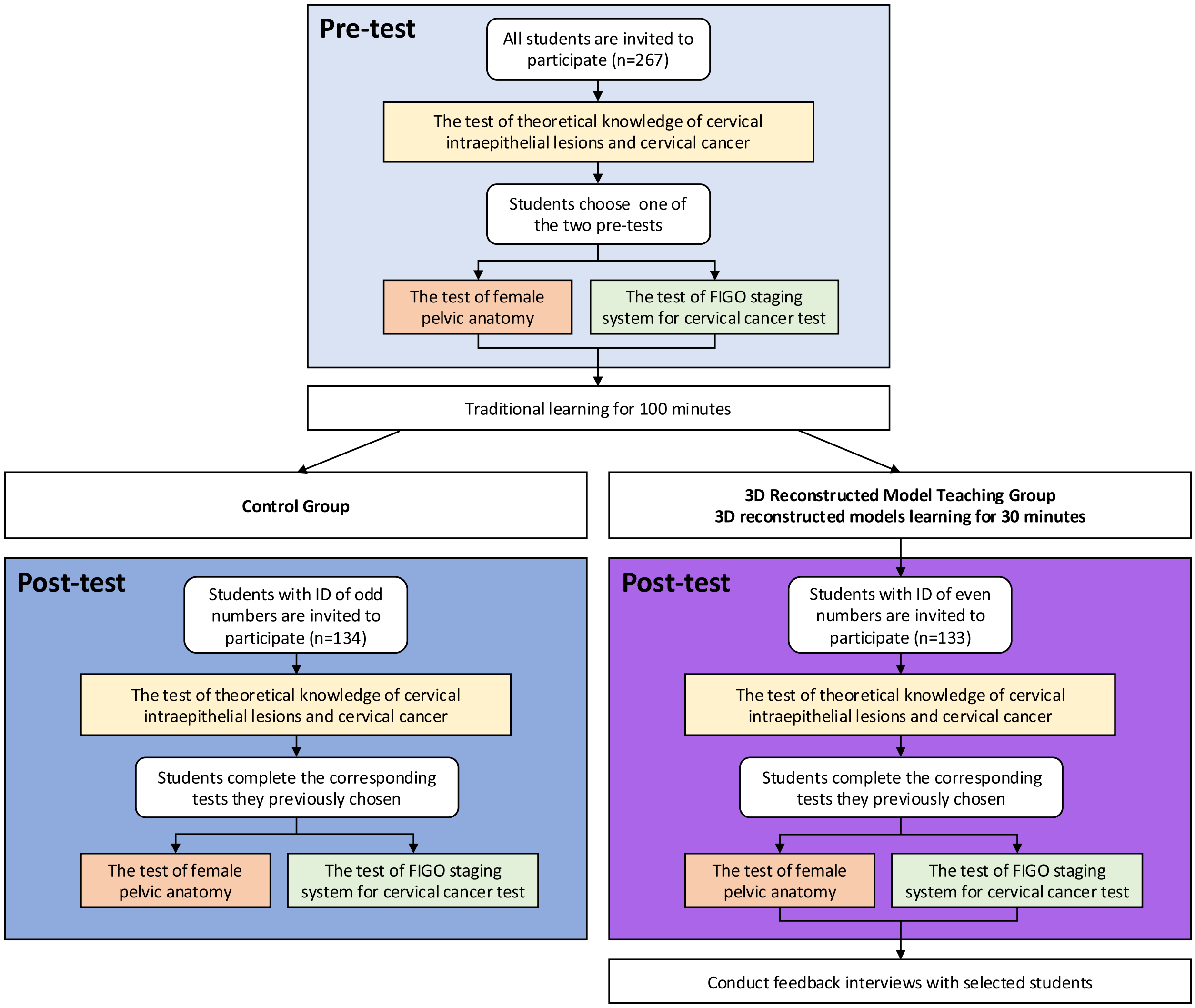

Fig. 2 Study flowchart

be selected for feedback interviews. If a selected student is absent, the selection will proceed to the next student in numerical order, and so on, until a student is present. For instance, if the student with ID number 2020305232080 is absent, the student with ID number 2020305232082 will be invited for the interview.

Data collection and analysis

Statistical analyses were conducted utilizing the SPSS software (version 25.0; IBM Corp.), with statistical significance being assigned to differences at two-sided P values below 0.05. The total scores of the pre-test and post-test were compared using Student's t-test.

Results

The 2020 grade of Clinical Medicine in the School of Medicine, Wuhan University includes 267 students, consisting of 129 males and 138 females with a gender ratio of 1.07. Their ages range from 19 to 23 years old, with an average age of 21.2 years.

The pre-test and post-test scores of the control group

The control group consists of 134 students, who are from among the student numbers ranging from 2020305232001 to 2020305232267 and whose last three digits are odd numbers.

The test of theoretical knowledge of cervical intraepithelial lesions and cervical cancer: 118 students completed the pre-test with a score of 79.5 ± 20.1 (range: 20 to 100), and 106 students completed the post-test with a score of 84.2 ± 15.1 (range: 40 to 100), with a significant difference ($p < 0.05$). Additionally, 90 students completed both the pre-test and post-test, with pre-test scores of 79.5 ± 19.8 (range: 20 to 100) and post-test scores of 84.9 ± 15.2 (range: 30 to 100), with a significant difference ($p < 0.001$).

The test of female pelvic anatomy: 68 students completed the pre-test with a score of 78.5 ± 15.5 (range: 20 to 100), while 77 students completed the post-test with a score of 79.5 ± 15.4 (range: 40 to 100), showing no significant difference ($p > 0.05$). Additionally, 60 students completed both the pre-test and the post-test, scoring 77.3 ± 15.9 (range: 20 to 100) in the pre-test and 80.7 ± 14.6 (range: 40 to 100) in the post-test, indicating a statistically significant difference ($p < 0.05$).

The test of 2018 FIGO staging system for cervical cancer: 24 students completed the pre-test with a score of 55.0 ± 21.1 (range: 20 to 90), while 18 students completed the post-test with a score of 61.7 ± 21.7 (range: 20 to 90), showing no significant difference ($p > 0.05$). Among them, 18 students completed both the pre-test and the post-test. Their pre-test score was 54.4 ± 20.1 (range: 20 to 90), and their post-test score was 61.7 ± 21.7 (range: 20 to 90), showing no significant difference ($p > 0.05$). The pre-test and post-test scores of the control group were summarized in Fig. 3.

The pre-test and post-test scores of the 3D reconstructed model teaching group

The 3D reconstructed model teaching group consists of 133 students, who are from among the student numbers ranging from 2020305232001 to 2020305232267 and whose last three digits are even numbers.

The test of theoretical knowledge of cervical intraepithelial lesions and cervical cancer: 114 students completed the pre-test with a score of 80.4 ± 21.6 (range: 20 to 100), and 103 students completed the post-test with a score of 90.9 ± 17.1 (range: 30 to 100), with a significant difference ($p < 0.001$). Additionally, 78 students completed both the pre-test and post-test, with pre-test scores of 80.3 ± 20.5 (range: 20 to 100) and post-test

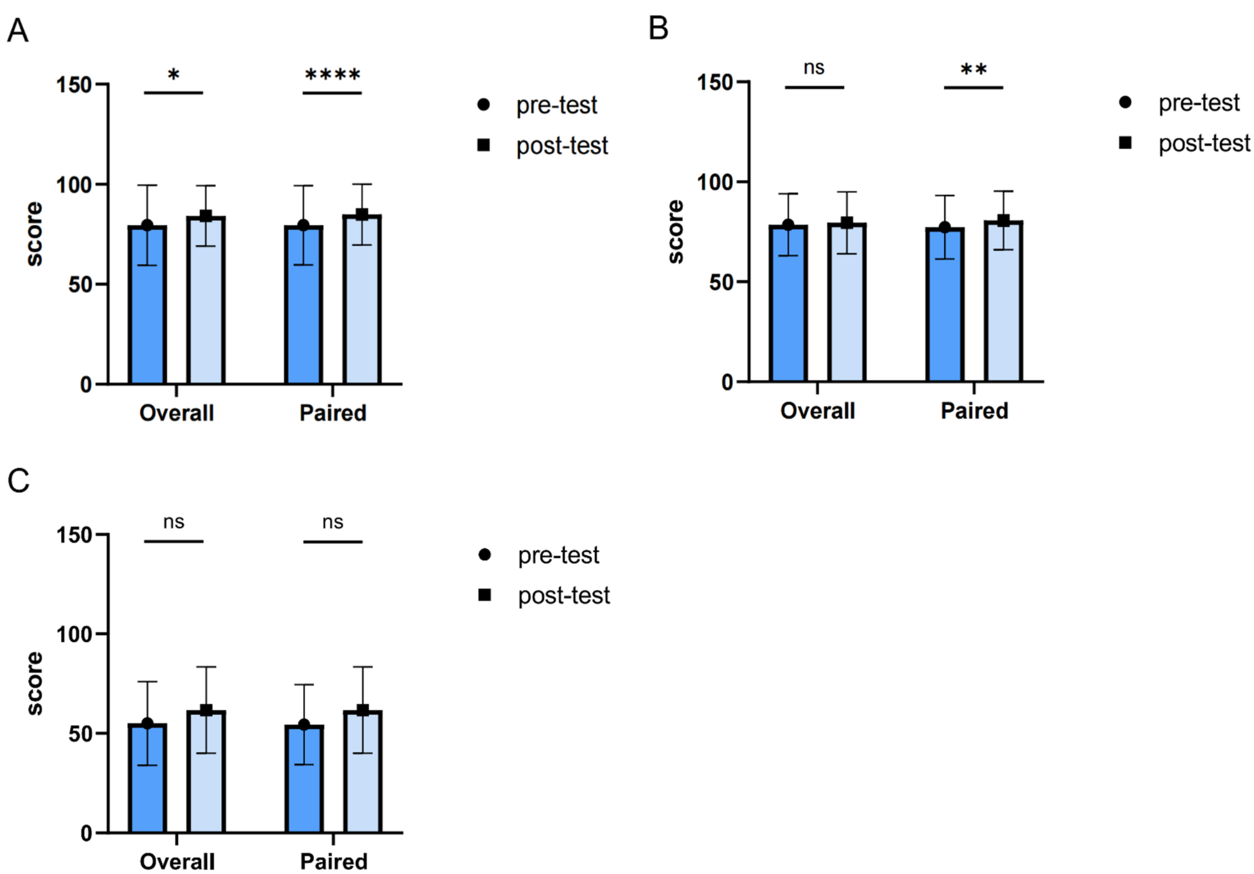

Fig. 3 The pre-test and post-test scores of the control group. **A** The test of theoretical knowledge of cervical intraepithelial lesions and cervical cancer. **B** The test of female pelvic anatomy. **C** The test of 2018 FIGO staging system for cervical cancer

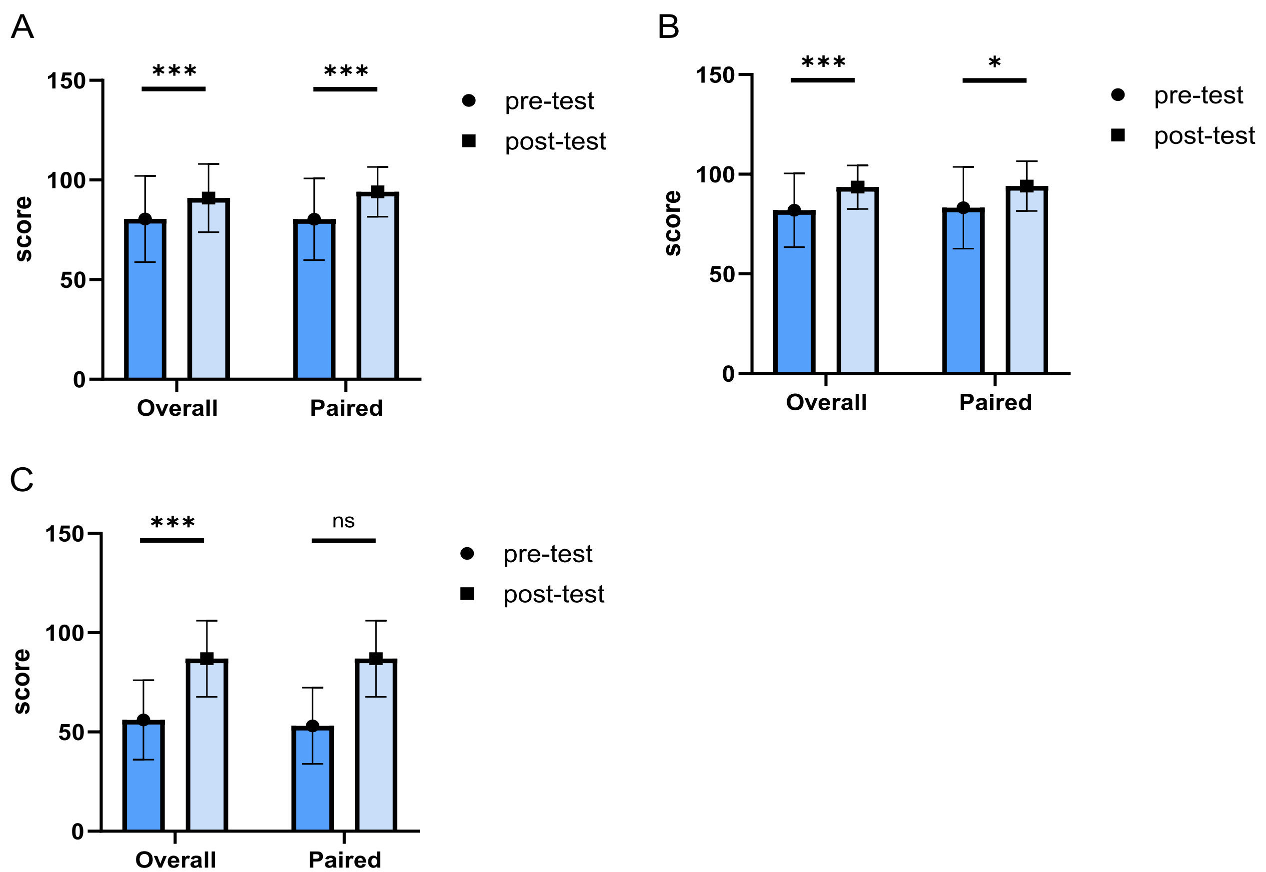

Fig. 4 The pre-test and post-test scores of the 3D reconstructed model teaching group. **A** The test of theoretical knowledge of cervical intraepithelial lesions and cervical cancer. **B** The test of female pelvic anatomy. **C** The test of 2018 FIGO staging system for cervical cancer

scores of 94.0 ± 12.5 (range: 30 to 100), with a significant difference ($p < 0.001$).

The test of female pelvic anatomy: 72 students completed the pre-test with a score of 81.9 ± 18.5 (range: 20 to 100), while 87 students completed the post-test with a score of 93.5 ± 10.9 (range: 40 to 100), with a significant difference ($p < 0.001$). Additionally, 56 students completed both the pre-test and the post-test, scoring 83.2 ± 20.5 (range: 20 to 100) in the pre-test and 94.0 ± 12.5 (range: 40 to 100) in the post-test, indicating a statistically significant difference ($p < 0.05$).

The test of 2018 FIGO staging system for cervical cancer: 18 students completed the pre-test with a score of 56.1 ± 20.0 (range: 20 to 90), while 16 students completed the post-test with a score of 86.9 ± 19.2 (range: 50 to 100), showing a significant difference ($p < 0.001$). Among them, 16 students completed both the pre-test and the post-test. Their pre-test score was 53.1 ± 19.2 (range: 20 to 90), and their post-test score was 86.9 ± 19.2 (range: 50 to 100). However, there was no statistically significant difference between the pre-test and post-test scores ($p > 0.05$). The pre-test and post-test scores of the 3D reconstructed model teaching group were summarized in Fig. 4.

The comparison of the paired pre-test and post-test scores of the two groups

Between the control group and the 3D reconstructed model teaching group, the paired pre-test scores for the theoretical knowledge of cervical intraepithelial lesions and cervical cancer were 79.5 ± 19.8 (range: 20 to 100) and 80.3 ± 20.5 (range: 20 to 100), respectively ($p > 0.05$); the paired pre-test scores for female pelvic anatomy were 77.3 ± 15.9 (range: 20 to 100) and 83.2 ± 20.5 (range: 20 to 100), respectively ($p > 0.05$); and the paired pre-test scores for FIGO staging were 54.4 ± 20.1 (range: 20 to 90) and 53.1 ± 19.2 (range: 20 to 90), respectively ($p > 0.05$). The paired pre-test scores of the two groups showed no statistical difference.

The test of theoretical knowledge of cervical intraepithelial lesions and cervical cancer: There were 90 paired pre- and post-test scores in the control group. The post-test scores increased by 5.3 ± 9.0 (range: −10 to 30) compared with the pre-test scores. There were 78 paired pre- and post-test scores in the 3D reconstructed model teaching group. The post-test scores increased by 13.7 ± 18.4 (range: −10 to 70) compared with the pre-test scores. The increase in the 3D reconstructed model teaching group was more significant than that in the control group ($p < 0.001$).

The test of female pelvic anatomy: There were 60 paired pre- and post-test scores in the control group. The post-test scores increased by 3.3 ± 8.1 (range: −20 to 30) compared with the pre-test scores. There were 56 paired pre- and post-test scores in the 3D reconstructed model teaching group. The post-test scores increased by 10.9 ± 18.9 (range: −30 to 70) compared with the pre-test scores. The increase in the 3D reconstructed model teaching group was more significant than that in the control group ($p < 0.05$).

The test of 2018 FIGO staging system for cervical cancer: There were 18 paired pre- and post-test scores in the control group. The post-test scores increased by 7.2 ± 18.1 (range: −20 to 40) compared with the pre-test scores. There were 16 paired pre- and post-test scores in the 3D reconstructed model teaching group. The post-test scores increased by 33.8 ± 27.3 (range: −20 to 70) compared with the pre-test scores. The increase in the 3D reconstructed model teaching group was more significant than that in the control group ($p < 0.05$).

The increase in post-test scores compared to pre-test scores between the two groups was summarized in Fig. 5.

Students' feedback

Thirteen students have shared their feedback on the 3D reconstructed models derived from real cases of cervical cancer, specifically designed for their gynecologic oncology teaching. Their perspectives are presented below, arranged in ascending order of student ID numbers:

- Student 1: "I think learning about cervical cancer through 3D reconstructed models is extremely effective. It's more intuitive and easier to understand compared to traditional teaching methods."
- Student 2: "The ability to manipulate the 3D model on my mobile device made the learning process more convenient and accessible."
- Student 3: "I found the 3D model to be a valuable tool for reinforcing my knowledge of female pelvic anatomy."

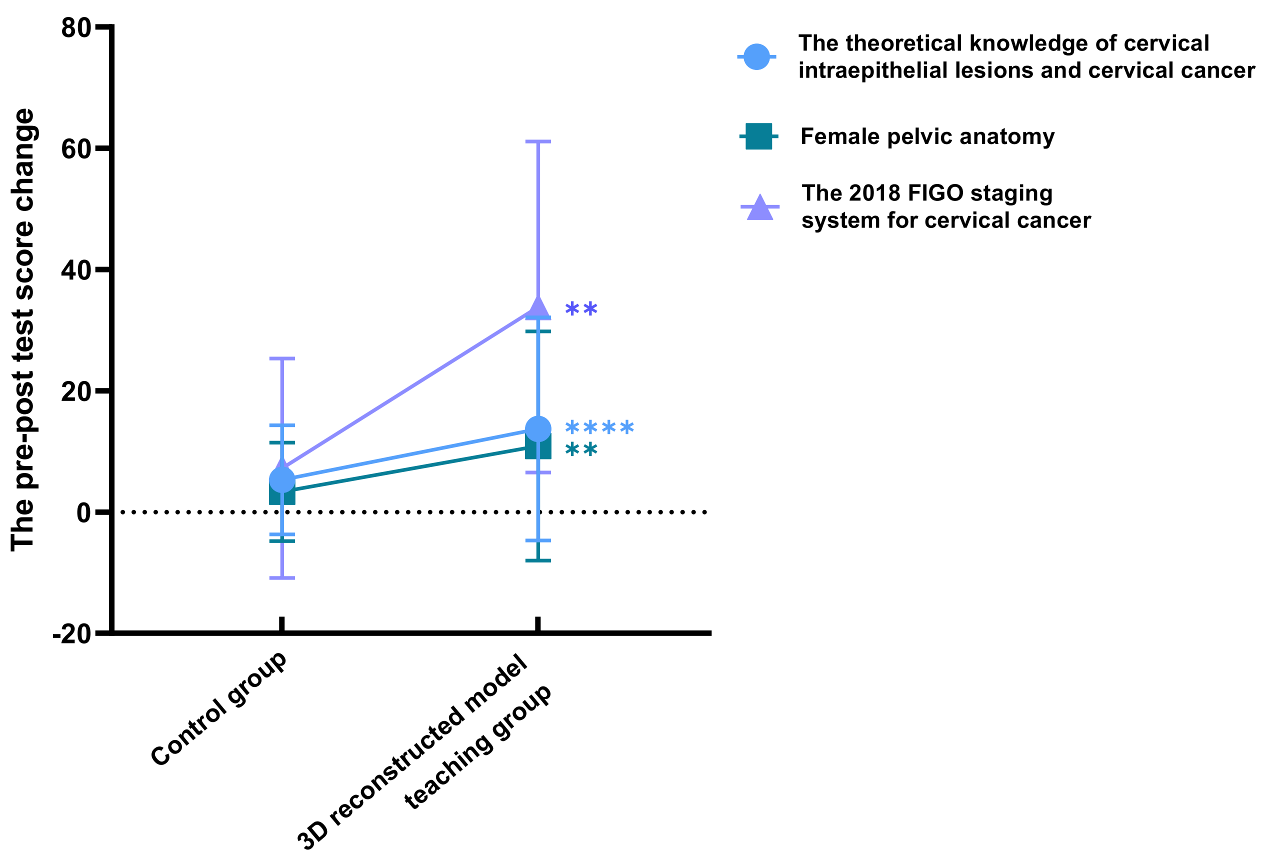

Fig. 5 The increase in post-test scores compared to pre-test scores between the two groups

- Student 4: “I appreciated the combination of traditional learning with the practical application of the 3D model, as it compensates for my lack of spatial imagination.”
- Student 5: “The 3D model provided a clearer representation of cervical cancer than traditional textbooks and diagrams.”
- Student 6: “The 3D reconstructed model allowed me to recall knowledge related to the female pelvic anatomy more quickly.”
- Student 7: “The 3D reconstructed model helped me connect the staging of cervical cancer with the extent of cervical involvement.”
- Student 8: “I believe the 3D model will be particularly beneficial for visual learners like myself.”
- Student 9: “The 3D model directly presents the content that needs to be learned and understood in this class.”
- Student 10: “The 3D reconstructed model allows me to see the progression of cervical cancer more intuitively, which helps me better understand its pathological changes.”
- Student 11: “I think this teaching tool is very innovative, which has inspired our interest in medical knowledge and enhanced our learning enthusiasm.”
- Student 12: “The use of the 3D reconstructed model in teaching cervical cancer has motivated me to explore more interactive learning tools in the future.”
- Student 13: The 3D reconstructed model has given me a clearer understanding of the diagnosis and treatment strategies for cervical cancer.

Among them, 7 students (Student 1, Student 4, Student 5, Student 8, Student 9, Student 10 and Student 13), accounting for 46.2% of the total participants, underscored the significant visual benefits that the teaching tool provided. They highlighted how the tool’s ability to present information in a visually stimulating and intuitive manner greatly enhanced their understanding and retention of the subject matter. Additionally, 3 students (Student 2, Student 11, and Student 12) demonstrated a keen interest in this novel teaching tool, finding it particularly engaging and promising for their learning process. Furthermore, 2 students (Student 3 and Student 6) and one student (Student 7) primarily expressed that the 3D reconstructed model helped them in learning the female pelvic anatomy and FIGO staging for cervical cancer.

Discussion

The integration of advanced technologies into medical education represents a significant advancement in addressing the complexities of teaching intricate subjects such as anatomy and gynecological oncology. In this investigation, we have introduced a novel learning tool: 3D reconstructed models based on real cervical cancer cases for undergraduate gynecological oncology education. Our primary objective is to assess its teaching effectiveness. We maintain that the conventional two-dimensional learning tools offer a limited perspective, whereas the 3D reconstructed models are apt at bridging this gap. These models provide medical students with a more intuitive and meticulous visualization of anatomical structures related to gynecological tumors, thus enhancing their learning experience.

The results of the pre-test and post-test in both the control group and the 3D reconstructed model teaching group provide valuable insights into the effectiveness of the teaching methods. Our study suggests that utilizing 3D reconstructed models significantly improved students’ comprehension and retention of knowledge regarding cervical intraepithelial lesions, cervical cancer, female pelvic anatomy, and the 2018 FIGO staging system for cervical cancer. The pre-test scores of the three tests between the control group and the 3D reconstructed model teaching group showed no statistical difference. This indicates the two groups of students had similar levels of knowledge at the beginning. Then, after receiving traditional teaching from the same professor in the same classroom, the innovative 3D reconstructed model teaching tool was used for the explanation of relevant content in 3D reconstructed model teaching group, while the control group did not.

The post-test scores in theoretical knowledge of cervical intraepithelial lesions and cervical cancer of both groups increased compared to the pre-test scores, indicating that traditional teaching is effective in increasing students’ knowledge. But the post-test scores of the 3D reconstructed model teaching group in this test increased more significantly than those of the control group, indicating that the innovative teaching tool has a synergistic effect on increasing students’ theoretical knowledge.

The post-test scores of the 3D reconstructed model teaching group in female pelvic anatomy and 2018 FIGO staging system for cervical cancer increased significantly compared to the control group, while the post-test scores of the control group in these tests did not show significant improvement. Regarding the effectiveness of 3D reconstructed models in helping students of the 3D reconstructed model teaching group learn the 2018 FIGO staging system for cervical cancer, the improvement in post-test scores compared to pre-test scores is not significant. This may be attributed to the complexity of the staging system itself, which places a heavy burden on memory, and the fact that medical undergraduates are currently not expected to master this staging system within their current curriculum. And the small number of students participating in this test may have also had an impact on the statistical results. Overall, the 3D reconstructed model is effective for students to master female pelvic anatomy, and the staging system of cervical cancer, highlighting its advantage as an innovative teaching tool used in the teaching of gynecological tumors in facilitating students' deeper understanding.

We believe that 3D reconstructed models have inherent advantages in elucidating the complex concepts and pathological processes related to gynecological tumors, and the feedback from the students of 3D reconstructed model teaching group also confirms this. By providing a visual and interactive representation, these models offer a more immersive learning experience, enabling students to grasp intricate anatomical structures and disease characteristics more effectively.

While virtual 3D reconstructions provide flexibility and interactivity, physical 3D-printed models can further complement these tools by offering a tactile and tangible learning experience. Together, these two approaches can cater to diverse learning styles, combining the visual depth of virtual models with the hands-on benefits of physical models.

The positive feedback from the students indicates a high level of satisfaction with the 3D reconstructed models. Feedback indicates that improved scores can largely be credited to the models' distinct visual superiority. These tools, characterized by their visual benefits, have already been extensively implemented in clinical practice. For instance, 3D MR images are used to automatically calculate liver volume [11], while 3D image reconstruction aids in thoracoscopic lobectomy and segmentectomy [12]. Cardiovascular interventions can be meticulously planned using a personalized 3D printing method for each patient [13]. Our earlier clinical researches back up these findings, which will not be dwelled upon here. Currently, these tools are making their way into medical education and are being well-received. 3D brain reconstruction can optimize surgical approaches for refractory epilepsy, while simultaneously enhancing medical education in minimally invasive neurosurgery for this challenging condition [14]. A study has shown that in the process of learning cardiac anatomy, the use of 3D models resonates more deeply with students, resulting in better outcomes on final tests when compared to the use of traditional models [15]. The utility of exposing medical students and healthcare professionals to 3D segmentation as part of their anatomical education lies in its additional benefit in enhancing their imaging interpretation ability [16]. Furthermore, 3D printing models and 3D virtual reconstructions are more effective in guiding interns' clinical education in hepatocellular carcinoma compared to 2D imaging [17]. In conclusion, the integration of 3D technology in medical education has been highly effective, as evidenced by the significant improvements in student performance and the enthusiastic feedback received.

This technology not only provides students with a more immediate and profound understanding of the subject matter but also makes the learning process more engaging and intuitive. The interactive nature of the 3D models allows students to explore and manipulate the anatomical structures, fostering a more hands-on and exploratory learning experience. 3D printed models, which are a physical manifestation based on 3D reconstructed models, have been demonstrated in studies to have the potential of improving patient education and understanding of their anatomy, disease, and treatment options [18, 19]. Beyond 3D reconstructions, a spectrum of interactive tools is being leveraged in medical education. In the era of digital learning, Massive Open Online Courses have significantly advanced medical education, allowing students to engage in self-directed learning beyond the confines of the traditional classroom setting [20]. And Virtual simulation technology is also widely used in a diverse range of medical skill learning scenarios, providing a safe environment for students to master clinical skills [21]. In short, interactive 3D models are revolutionizing medical education, making it more engaging, intuitive, and hands-on for students. Further research and integration of such technologies into medical curricula are warranted to continue enhancing the educational experience for future medical professionals in the digital age.

The study has limitations, including the small sample size and the limited range of diseases represented by the 3D reconstructed models. Future research could include a larger cohort of students and a broader spectrum of gynecological diseases to confirm the generalizability of these findings. Additionally, while this study focused on virtual 3D reconstructed models, exploring the application of physical 3D-printed models in clinical education could strengthen the link between theoretical learning and practical applications. By comparing physical 3D-printed models with virtual reconstructions in different educational scenarios, future studies may uncover further advantages of tactile learning tools, particularly in facilitating anatomical comprehension and spatial visualization.

Conclusion

Our study demonstrates the potential of 3D reconstructed models derived from real clinical cases as valuable adjuncts to traditional teaching methods in gynecological oncology. By providing students with immersive and interactive learning experiences, these models enhance understanding, retention, and engagement. The ease of access to such technology, coupled with its intuitive and interactive nature, suggests that it could become a valuable tool in medical education, not only for anatomy but for a wide range of medical disciplines. Further research and integration of such technologies into medical curricula are warranted to continue enhancing the educational experience for future medical professionals. This innovative approach to medical education aligns with the digital and technological advancements characterizing the new era of medical learning, ultimately contributing to the advancement of medical education in the digital age.

Abbreviations

3D	Three-dimensional
FIGO	International Federation of Gynecology and Obstetrics
QR	Quick Response
ID	Identity document

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s41205-025-00256-z.

Supplementary Material 1.

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Authors' contributions
ZJJ, SM and HZ developed the concept and designed the study. LXY were involved in the production of the 3D reconstructed model. ZJJ was responsible for the classroom application of the 3D reconstructed models and the design of the test questions. HZ completed the traditional classroom teaching about cervical intraepithelial neoplasia and cervical cancer. KLY created the QR codes used in this study, KLY and HYY collected and analyzed the data. ZJJ and HYY drafted the manuscript. All authors contributed to the iterative drafting and refinement of the manuscript. All authors approved the final version of the manuscript for submission.

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Data availability
Data used in the present study are available within this published article. The SPSS raw dataset may be available upon reasonable request. Applicants should contact the following email address 'huzheng1998@163.com' to request. The reply will be communicated within 1 week from the request.

Declarations

Ethics approval and consent to participate
Study participation was voluntary, and students provided written informed consent to participate in the study. This study complied with the tenets of the Declaration of Helsinki, i.e. no identifying information was stored, and all data were deleted following analysis. According to the guidelines of Wuhan University's board of physicians review, analysis of such data does not require specific approval by the ethics committee.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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References

1. Tokuç B, Varol G. Medical Education in the Era of Advancing Technology. Balkan Med J. 2023;40(6):395–9.
2. Venkatesan M, Mohan H, Ryan JR, Schürch CM, Nolan GP, Frakes DH, Coskun AF. Virtual and augmented reality for biomedical applications. Cell Rep Med. 2021;2(7): 100348.
3. Idoga PE, Toycan M, Nadiri H, Çelebi E. Assessing factors militating against the acceptance and successful implementation of a cloud based health center from the healthcare professionals' perspective: a survey of hospitals in Benue state, northcentral Nigeria. BMC Med Inform Decis Mak. 2019;19(1):34.
4. Dmytryshyn J, Selk A. Learning on the Go: Assessing Knowledge Gained From Medical Podcasts Created for Vulvovaginal Disease Education. J Low Genit Tract Dis. 2022;26(2):164–8.
5. Han ER, Yeo S, Kim MJ, Lee YH, Park KH, Roh H. Medical education trends for future physicians in the era of advanced technology and artificial intelligence: an integrative review. BMC Med Educ. 2019;19(1):460.
6. Keenan ID, Ben Awadh A. Integrating 3D Visualisation Technologies in Undergraduate Anatomy Education. Adv Exp Med Biol. 2019;1120:39–53.
7. Bhatla N, Berek JS, Cuello Fredes M, Denny LA, Grenman S, Karunaratne K, Kehoe ST, Konishi I, Olawaiye AB, Prat J, et al. Revised FIGO staging for carcinoma of the cervix uteri. Int J Gynaecol Obstet. 2019;145(1):129–35.
8. Zhang J, Cao D, Yang J, Shen K, He Y, Xue H. Tumor Volume Predicts High-Risk Patients and Guides Initial Chemoradiotherapy for Early Cervical Cancer. Front Oncol. 2021;11:640846.
9. Zhang J, Wang Y, Cao D, Shen K. MRI-based three-dimensional reconstruction for staging cervical cancer and predicting high-risk patients. Ann Transl Med. 2021;9(18):1398.
10. Bhatla N, Aoki D, Sharma DN, Sankaranarayanan R. Cancer of the cervix uteri. Int J Gynaecol Obstet. 2018;143(Suppl 2):22–36.
11. Le TN, Bao PT, Huynh HT. Fully automatic scheme for measuring liver volume in 3D MR images. Bio-Med Mater Eng. 2015;26(Suppl 1):S1361–1369.
12. Yao F, Wang J, Yao J, Hang F, Lei X, Cao Y. Three-dimensional image reconstruction with free open-source OsiriX software in video-assisted thoracoscopic lobectomy and segmentectomy. Int J Surg (London, England). 2017;39:16–22.
13. Uccheddu F, Gallo M, Nocerino E, Remondino F, Stolcova M, Meucci F, Di Mario C, Gerosa G. Cardiovascular interventions planning through a

three-dimensional printing patient-specific approach. J Cardiovasc Med (Hagerstown). 2019;20(9):584–96.
14. Swaminathan A. Three Dimensional Brain Reconstruction Optimizes Surgical Approaches and Medical Education in Minimally Invasive Neurosurgery for Refractory Epilepsy. Front Surg. 2021;8: 630930.
15. Lim KH, Loo ZY, Goldie SJ, Adams JW, McMenamin PG. Use of 3D printed models in medical education: A randomized control trial comparing 3D prints versus cadaveric materials for learning external cardiac anatomy. Anat Sci Educ. 2016;9(3):213–21.
16. Jinga MR, Lee RBY, Chan KL, Marway PS, Nandapalan K, Rhode K, Kui C, Lee M. Assessing the impact of 3D image segmentation workshops on anatomical education and image interpretation: A prospective pilot study. Anat Sci Educ. 2023;6:1024.
17. Cheng J, Wang ZF, Yao WF, Liu JW, Lu Y, Wang Q, Cai XJ. Comparison of 3D printing model to 3D virtual reconstruction and 2D imaging for the clinical education of interns in hepatocellular carcinoma: a randomized controlled study. J Gastrointest Oncol. 2023;14(1):325–33.
18. Scherer-Quenzer AC, Beyers I, Kalisz A, Sauer ST, Zimmermann M, Wöckel A, Polat B, Schlaiss T, Schelbert S, Kiesel M. Evaluating the value of individualized 3D printed models for examination, diagnosis and treatment planning of cervical cancer. 3D Print Med. 2024;10(1):25.
19. Wake N, Rosenkrantz AB, Huang R, Park KU, Wysock JS, Taneja SS, Huang WC, Sodickson DK, Chandarana H. Patient-specific 3D printed and augmented reality kidney and prostate cancer models: impact on patient education. 3D Print Med. 2019;5(1):4.
20. Gong Z. The development of medical MOOCs in China: current situation and challenges. Med Educ Online. 2018;23(1):1527624.
21. Wu Q, Wang Y, Lu L, Chen Y, Long H, Wang J. Virtual Simulation in Undergraduate Medical Education: A Scoping Review of Recent Practice. Front Med (Lausanne). 2022;9: 855403.

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