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Effect of flipped classroom to anesthesia crisis management simulation education: a quasi-experimental study

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Abstract

Background While simulation is widely employed in anesthesia crisis management training, its effectiveness is often hindered by lack of preparation. Flipped classroom (FC) is a novel teaching method that encourages active student engagement and preparation. We aim to investigate whether FC could enhance the residents' engagement in preparation activities and improve the learning outcomes in anesthesia crisis management simulation.

Methods This quasi-experimental study included anesthesiology residents from the anesthesiology department, Shanghai General Hospital between January 2023 and July 2023. The participants were randomly divided into the FC group and the conventional lecture (CL) group. The primary outcome was the Anesthetists' Non-Technical Skills (ANTS) scores of all participants. Secondary outcomes included crisis response performance, theoretical test scores, and time spent on training-related activities.

Results A total of 40 anesthesiology residents in their first two postgraduate years at Shanghai General Hospital were recruited for analysis. The FC group ($n = 20$) achieved significantly higher overall ANTS scores (FC vs. CL: 11.95 ± 2.14 vs. 9.55 ± 2.40, $p = 0.002$) than the CL group. The FC group had higher correct response rates in two out of six observational checkpoints in the simulation (FC vs. CL: 'Recognize acute pulmonary embolism and deal with it accordingly', 95% vs. 60%, $p = 0.020$; 'Provide circulatory support and heparin treatment', 100% vs. 75%, $p = 0.047$). The FC group also obtained higher post-training theoretical test scores (FC vs. CL: 90.9 ± 4.8 vs. 84.8 ± 7.8, $p = 0.005$) than the CL group. While the FC group spent more time studying before the simulation session (FC vs. CL (mean [min, max]): 2.6 [1.3, 3.6] vs. 1.3 [0.3, 2.3], $p < 0.0001$), there was no significant difference in total studying time between the two groups (FC vs. CL (mean [min, max]): 3.6 [2, 5.6] vs. 3.4 [1.8, 4.9], $p = 0.418$).

Conclusion FC may improve the learning performance in the management of perioperative pulmonary embolism within anesthesia crisis management simulation training compared to CL-based learning.

Trial registration The study was registered with No. ChiCTR2300070086.

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Keywords Anesthesia crisis management, Training, Residents, Quasi-experimental study

Background

Advances in pharmacology, understanding of human physiology, and monitoring techniques have significantly improved the safety of anesthesia in recent years, leading to a steady decline in anesthesia-associated mortality [1–3]. However, various life-threatening emergencies, such as hypotension [4], tachycardia [5], pulmonary embolism, airway complications [6], allergic reactions [7], or even equipment malfunctions, may still occur during anesthesia with little or no warning [8]. Effective anesthesia crisis management is therefore crucial in the operating room, demanding that anesthetists must possess sufficient knowledge and practical skills to handle these emergencies [8]. Essential competencies include understanding of the conditions of the patient, extensive pharmacological and physiological background, proficient information-gathering and pattern recognition skills, fast decision-making ability, and strong communication and teamwork skills. These requirements further necessitate the need for high-quality training in anesthesia crisis management.

In order to enhance the training quality of anesthesia crisis management, various anesthesia crisis management classes, guidelines, and training programs have been developed [8–10]. Among these, simulation-based training has emerged as a critical tool in anesthesia education [11]. In a simulation training program, trainees will be asked to take appropriate measures to handle anesthesia crises in a simulated operating room under realistic scenarios (e.g., cases derived from previous patients), with different patient conditions taken into consideration [12]. Through simulation-based training, trainees are expected to gain more hands-on experience and clinical skills, ultimately reducing the likelihood of medication errors made during anesthesia administration [13]. Previous studies have demonstrated the advantages of simulation-based training among anesthesia residents and pre-clinical students [12, 14]. Importantly, simulation often requires the participants to complete preparation activities prior to the training session, which can improve the outcomes of the training [15]. Unfortunately, lack of preparation and reviewing is often observed among many residents or students, which can impede the desired learning outcomes. It is, therefore, necessary to enhance the trainees' motivation and participation in preparation to maximize the benefit of simulation-based training.

The 'flipped classroom' (FC) approach has become increasingly popular in medical education due to its ability to markedly improve student learning in medical education by enhancing their motivation, retention, and engagement [16–19]. In FC, rather than a typical lecture-homework pattern, students are asked to watch pre-recorded lectures before the class and perform active learning activities, including group presentations, exercises, and projects, with the educator during the class to achieve the training goal [17]. Whether FC is beneficial in medical education remains controversial [20–24]; however, FC may improve teaching results in subjects involving hands-on sessions and teamworking, such as surgery [22, 23]. Hence, FC may improve simulation-based anesthesia crisis management education, because the presentation and team discussion may improve the students' resilience and confidence, encouraging them to perform better in a stressful environment. In this study, we aim to investigate whether FC could enhance the residents' engagement in preparation activities and improve the learning outcomes in anesthesia crisis management simulation.

Methods

Design and subjects

A pilot educational study was conducted in the Simulation Teaching Center of Shanghai General Hospital with anesthesiology residents from January to July 2023. Convenience sampling was used to recruit participants via hospital media advertisements in September 2022. Inclusion criteria included (1) anesthesilogy resident in first two post-graduation years under standardized training at Shanghai General Hospital; and (2) had no previous experience in anesthesia crisis management simulation. Exclusion criteria included (1) conditions deemed unsuitable for inclusion, such as mental or physical health issues identified by the instructors as impairing the participants' ability to take part in this study. A total of 40 anesthesiology residents were recruited and randomly assigned into two groups: the Conventional Lecture (CL) group ($n=20$) and the FC group ($n=20$). Written informed consent was obtained from all residents who agreed to participate in the study. The study was approved by the Medical Ethics Committee of Shanghai General Hospital (Approval No. 2022KY136) and was registered and performed following the ethical regulations of Shanghai General Hospital for medical education.

Intervention

Pre-training test

Before the training, all participants completed a pre-class theoretical examination on perioperative pulmonary embolism consisting of 20 multiple-choice questions with a total mark of 100 points.

Flipped classroom training

The FC group was instructed to watch a video of learning materials before the program two weeks before the in-class session. The pre-recorded video introduced learning objectives and contents related to the diagnosis and treatment of perioperative pulmonary embolism. Two related questions were attached after the video. Participants were then asked to form discussion groups of five, and each group was asked to prepare for a team presentation. The themes of the presentation were determined by individual groups but were suggested to include discussions on the two questions. In the third week, all small groups individually attended a 30-minute in-class session consisting of case-based discussion. After a brief introduction by the teacher, the group was given a clinical case related to perioperative pulmonary embolism. The group was then asked to make a 15-minute presentation during the classroom session, combining the previously prepared contents and the ad hoc discussion (approximately 3 min for each participant). All groups were asked to submit a document compiling all the answers to the questions posed along with the clinical case. The teacher provided the students with feedback based on their submitted document.

Conventional classroom training

The CL group was encouraged to preview the same material, including the videos shown to the FC group before attending the lecture in the first two weeks (two questions identical to the FC group were also attached to the video). In the third week, the students attended a 30-minute conventional lecture, followed by a 15-minute question-and-answer session. After class, the instructor assigned homework involving the same two questions after the video clip and the clinical case discussed in the FC. The teacher provided the students with feedback based on their submitted homework.

Simulation case operation

We recruited four trained teachers who were teaching faculty at Shanghai General Hospital to run the simulated case with standardized procedures, including prebriefing, simulation and debriefing. Standardized teaching guides for teachers were developed and reviewed before each simulation session. The students in both groups were asked to form random teams of two within the group and participate in a 45-minute simulation, which involved an orthopedic patient with a sudden decline of end-tidal carbon dioxide tension as the clinical manifestation of pulmonary embolism (Fig. 1). The simulation was performed in a simulated operating room at the Simulation Training Center, equipped with SIM3G human patient simulator with integrated cardiac monitoring, simulated anesthesia machine, defibrillator, and other relevant equipment. High-fidelity simulation was employed to recreate a scenario of anesthesia crisis management. The scenario involved an elderly female patient undergoing a total hip arthroplasty who experienced a sudden pulmonary embolism during the procedure. The crisis was simulated using preprogrammed vital signs on the SIM3G patient simulator, simulated cardiac monitoring, and predefined diagnostic results. The participants were allowed to perform clinical interventions, including auscultation, intubation, cardiopulmonary resuscitation (CPR), vascular access, and drug administration. All necessary simulation materials, including equipment and medications, were provided during the training. The instructor, blinded to the groups, assessed crisis response performances based on an objective assessment checklist of six items. Each participant was assessed individually by the instructor. Video recordings of all participants during the simulation sessions were captured for rating. The chronology of the FC and CL teaching sessions is summarized in Fig. 2.

Rating procedure

Videos of each simulation were assessed by four raters, who were blinded to the purpose of the study and were unfamiliar with the participants in the simulation scenarios. Each participant was rated individually by all raters. The raters were qualified simulation instructors selected from the faculty and were trained by the study investigators in rating. The raters were instructed to use the Anesthetists' Non-Technical Skills (ANTS) scoring system to rate each participant [25]. The ANTS rating systems use a 4-point scoring system to quantify the behaviors in four aspects, including situation awareness, decision making, task management and teamwork [25]. Each aspect was rated with a number between 1 and 4 (1, poor; 2, marginal; 3, acceptable; 4, good) [26]. The overall score ranged from 4 to 16 for each participant. The names and dates of the videos were redacted, and the order was randomized. The raters reviewed each video and identified clearly the participant to be assessed in each simulation. The raters assessed each video independently and did not compare their results.

Post-training test

All participants were asked to complete a post-class theoretical examination on perioperative pulmonary embolism consisting of 20 multiple-choice questions with a total mark of 100 points. The questions in this test were randomly selected from the same question library as the pre-training test. There were 20% overlapping questions between the two tests. Before the post-training test, two investigators independently reviewed the questions in both tests and confirmed that they covered similar key points involved in the training and were of comparable difficulty levels.

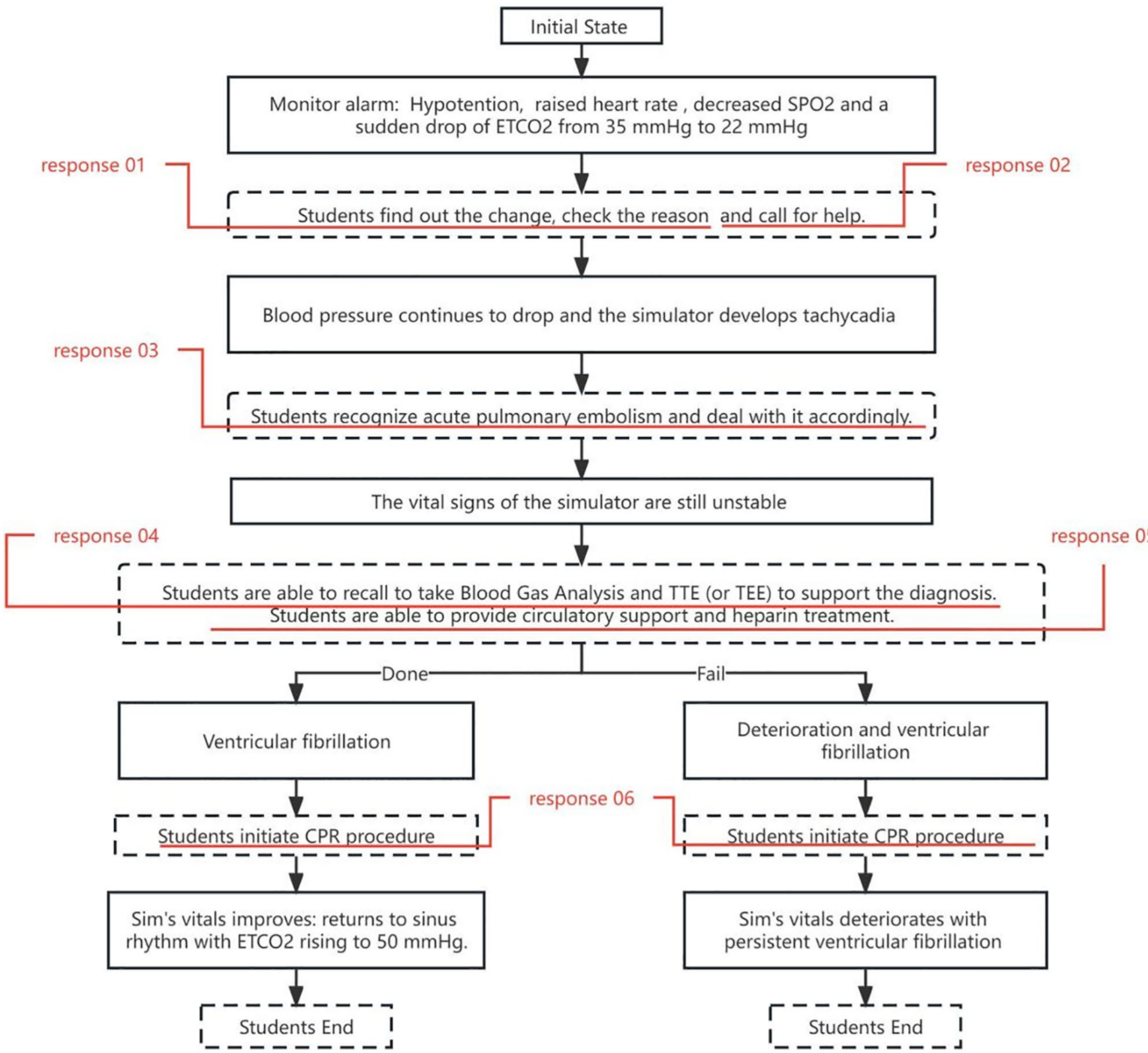

Fig. 1 Flow chart of the pulmonary embolism case in simulated anesthesia crisis management. ECG, electrocardiogram; SPO2, pulse oxygen saturation; ETCO2, end-tidal carbon dioxide tension; TTE, transthoracic echocardiography; TEE, transesophageal echocardiography; CPR, cardiopulmonary resuscitation

Outcomes

The primary outcome was the ANTS scores of all participants. Secondary outcomes included crisis response performance, theoretical test scores, and time spent on training-related activities. *Crisis response performance*: The simulation instructor used a modified process-specific checklist of six related key events and evaluated each participant's corresponding responses at every checkpoint. *Theoretical test scores*: The scores of both pre- and post-training tests. *Time spent on training-related activities*: The time used by each participant to complete all studying tasks related to this training program, excluding the time spent in class. All participants were asked to record their studying time related to this course, including pre-class preparation and post-class reviewing times, through our online studying platform. This platform was designed for online teaching and process management of learning activities, providing access to the videos and other learning materials via online portals. Students were required to complete their pre-class learning exclusively through the platform or access relevant materials via platform-linked internet portals. Specifically, the video playing time for each participant was recorded and the course-related questions were only shown after 95% of the video clip was played. The platform was also used to complete assignments, search for materials, and review

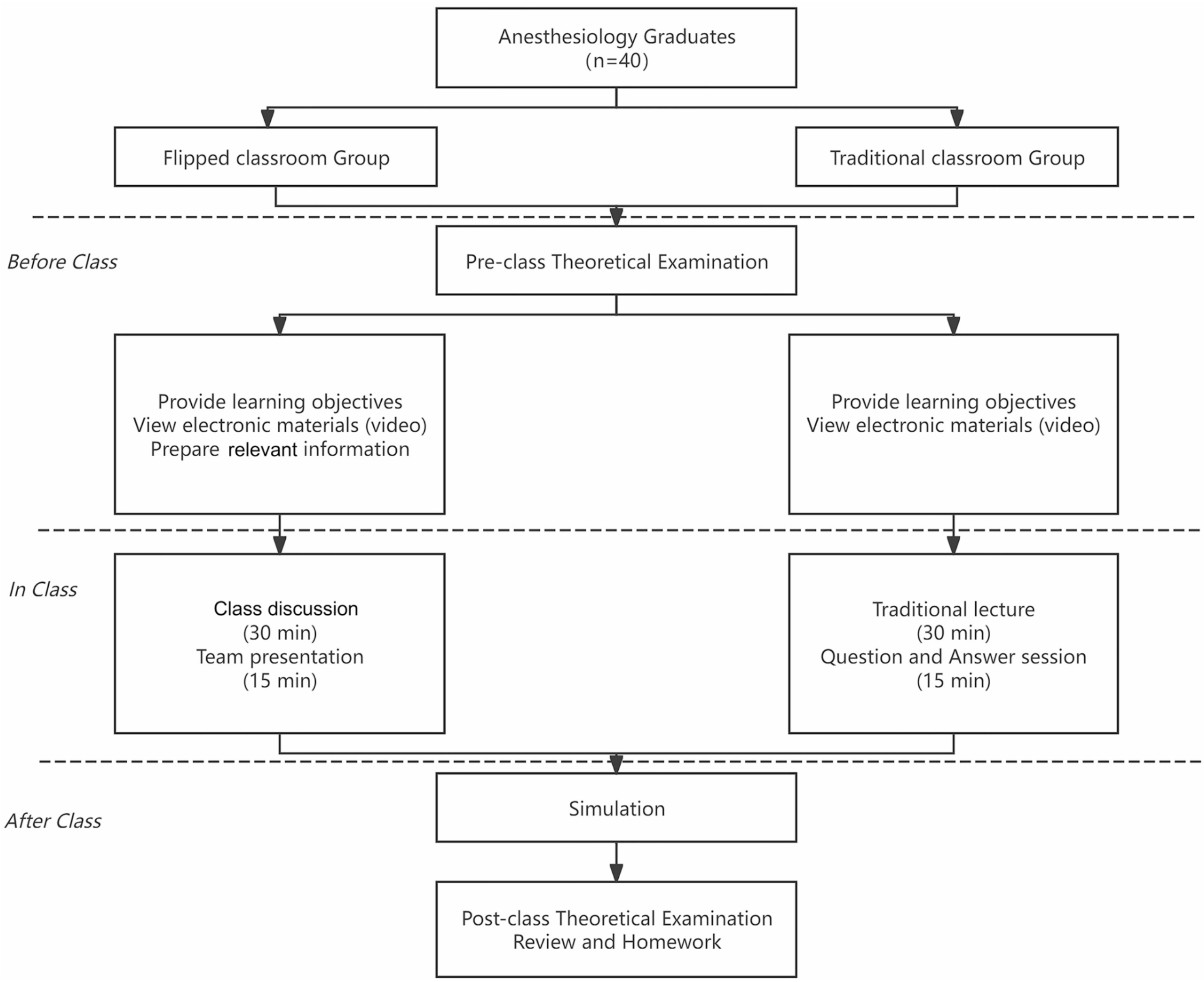

Fig. 2 Flow diagram of the flipped classroom (FC) and conventional lecture (CL) models

course content. All post-class activities were carried out and recorded through the platform, ensuring consistent tracking of study times.

Statistical analysis

All data were analyzed using the Statistical Package for Social Sciences (SPSS, version 20). Percentages with numbers in parentheses were used to present categorical data. Continuous data were presented as mean ± standard deviation (SD). Statistical data on time was presented as mean [min, max]. Independent sample *t*-test and two-way ANOVA analysis were used to compare the differences between two normally distributed groups; Mann-Whitney U test was used to compare non-normally distributed groups. To evaluate the FC's effects on each crisis management simulation performance, we conducted a chi-square analysis using 2 × 2 cross tables. A two-sided *p*-value below 0.05 was considered statistically significant.

Table 1 Basic characteristics

	CL	FC
Male, n (%)	8 (40)	7 (35)
Age (yr)	24.9 ± 1.9	24.75 ± 1.9
Grade (PGY 2/ PGY 3)	11/9	10/10

CL: Conventional lecture-based classroom group; FC: flipped classroom group; PGY: post-graduation year

Results

The baseline characteristics of the 40 residents are shown in Table 1. Approximately 40% of the participants were male and the mean ages were 24.9 ± 1.9 and 24.75 ± 1.9 for the CL and FC groups, respectively. There were no significant differences in gender, grade, or age between the two groups.

The FC group showed significantly higher overall ANTS scores compared with the CL group (FC vs. CL: 11.95 ± 2.14 vs. 9.55 ± 2.40, $p = 0.002$) (Table 2). The ANTS scores of the FC group in 'Decision making',

Table 2 Anesthetists' Non-Technical skills (ANTS) performance scores between the two groups

	CL	FC	P
Situation awareness	2.95 ± 1.00	3.10 ± 0.97	0.632
Decision making	2.10 ± 1.07	2.90 ± 0.97	0.018
Team-working and leadership	2.40 ± 0.94	3.20 ± 0.83	0.007
Task management	2.10 ± 0.79	2.75 ± 1.12	0.040
Overall score[#]	9.55 ± 2.40	11.95 ± 2.14	0.002

CL: Conventional lecture-based classroom group; FC: flipped classroom group. The maximum score for each subcategory is 4. [#]Sum of subcategory scores (maximum 16)

Table 3 Corresponding responses in crisis management simulation

	Group			
	CL	FC	Total	P
Response 01	Recognize the situation, check for reason quickly			
Pass	18	20	38	0.487
Fail	2	0	2	
Response 02	Call for help			
Pass	14	15	29	1.000
Fail	6	5	11	
Response 03	Recognize acute pulmonary embolism and deal with it accordingly			
Pass	12	19	31	0.020
Fail	8	1	9	
Response 04	Take Blood gas analysis and TTE (or TEE) to support the diagnosis			
Pass	9	13	22	0.341
Fail	11	7	18	
Response 05	Provide circulatory support and heparin treatment			
Pass	15	20	35	0.047
Fail	5	0	5	
Response 06	Perform CPR procedure			
Pass	12	16	28	0.301
Fail	8	4	12	

CL: Conventional lecture-based classroom group; FC: flipped classroom group; TTE: transthoracic echocardiography; TEE: transesophageal echocardiography; CPR: cardiopulmonary resuscitation

'Team-working and leadership', and 'Task management' were all higher than those in the CL group (FC vs. CL: 2.90 ± 0.97 vs. 2.10 ± 1.07, $p = 0.018$; 3.20 ± 0.83 vs 2.40 ± 0.94, $p = 0.007$; 2.75 ± 1.12 vs 2.10 ± 0.79, $p = 0.040$). There was no significant difference between the two groups in 'Situation awareness' ANTS scores (FC vs. CL: 3.10 ± 0.97 vs. 2.95 ± 1.00, $p = 0.632$).

Among the six observational items in the crisis response assessment, most participants passed Response 01 ($n = 38$, 95.0%), whereas Response 04 showed the lowest pass rates among all checkpoints ($n = 18$, 55.0%). The pass rates of Responses 03, 'Recognize acute pulmonary embolism and deal with it accordingly', and Response 05, 'Provide circulatory support and heparin treatment', were significantly higher in the FC group than in the CL group (FC vs. CL: 'Recognize acute pulmonary embolism and deal with it accordingly', 95% vs. 60%, $p = 0.020$; 'Provide circulatory support and heparin treatment', 100% vs. 75%, $p = 0.047$). No significant difference was observed between the two groups in other responses (Table 3).

Table 4 Theoretical performance and learning time

	CL	FC	*p* value*
Theoretical performance			
Pre-class	72.8 ± 10.6	72.5 ± 12.3	0.945
Post-class	84.8 ± 7.8	90.9 ± 4.8	0.005
Prepare and review time			
Pre-class time (h) [min, max]	1.3 [0.3, 2.3]	2.6 [1.3, 3.6]	< 0.0001
Post-class time (h) [min, max]	2.1 [1, 3.6]	1.0 [0.5, 2.5]	< 0.0001
Total time (h) [min, max]	3.4 [1.8, 4.9]	3.6 [2, 5.6]	0.418

CL: Conventional lecture-based classroom group; FC: flipped classroom group

The scores of the theoretical examination in the FC group before the training session were not statistically different from the CL group (FC vs. CL: 72.5 ± 12.3 vs. 72.8 ± 10.6, $p = 0.945$) (Table 4). While both groups achieved higher scores in the post-training test compared with the pre-training test, the FC group showed a significantly higher mean score in the post-training test than the CL group (FC vs. CL: 90.9 ± 4.8 vs. 84.8 ± 7.8, $p = 0.005$).

The preparation time in the FC group was significantly longer than the CL group (FC vs. CL (mean [min, max]): 2.6 [1.3, 3.6] vs. 1.3 [0.3, 2.3], $p < 0.0001$), while the post-class review time was significantly shorter in FC group (FC vs. CL (mean [min, max]): 1.0 [0.5, 2.5] vs. 2.1 [1, 3.6], $p < 0.0001$). There was no significant difference in the overall time spent between the two groups (FC vs. CL (mean [min, max]): 3.6 [2, 5.6] vs. 3.4 [1.8, 4.9], $p = 0.418$).

Discussion

In this study, we demonstrated that the FC method can improve the results of simulation-based anesthesia crisis management training, using perioperative pulmonary embolism as a showcase. Specifically, the residents in the FC group showed higher ANTS scores compared with the group that followed a conventional learning pattern; the FC group also showed a higher rate of correct responses to critical events in anesthesia crisis and achieved better post-training exam results without spending more time learning the entire training program. These results collectively show that introducing FC in simulation-based anesthesia crisis management training may be a successful strategy, which can significantly enhance residents' theoretical and practical performance in the management of perioperative pulmonary embolism.

Simulation is increasingly popular in medical training programs to meet students' learning needs and emphasize non-technical ability. Simulation-based training provides a unique opportunity for healthcare professionals to practice and assess crisis management behaviors in realistic clinical scenarios in a controlled environment [27]. However, under conventional learning patterns, insufficient preparation is often observed among students and young residents who have limited time for these activities, which hinders the effectiveness of simulation-based training. To overcome this challenge, our study employed a complete and specific training plan to integrate the FC approach into the pre-simulation preparation activities, demonstrating a significant enhancement in training effectiveness, especially in non-technical skills as quantified by the ANTS system.

Multiple factors may have contributed to the higher ANTS scores in FC group. Firstly, the FC group had more freedom and flexibility in self-directed learning compared with the CL group [28]. Hence, students may discuss certain questions and unclear points prior to the class, which may then be answered by the teacher specifically during the class. Secondly, the FC promoted interactions between learners. The pre-class preparation and in-class activities, such as small-group discussions, could promote peer interactions that improve their teamwork and leadership [29, 30], as reflected by the ANTS scores ('Team-working and leadership'). This may have also led to better 'task management' in the ANTS scores as well as better knowledge perception, as indicated by the higher post-training test scores in the FC group. Thirdly, we employed a video-based training approach in the FC group, which provided comprehensive and immersive training content. Several studies have also demonstrated the benefits of video-based training prior to simulation or hands-on sessions [22, 23]. In addition, the FC group showed higher theoretical test scores than the CL group after the training session. This agrees with a previous study on pharmaceutical calculation skills [20], but is inconsistent with another study on ophthalmology education, where the FC training did not improve the students' test scores compared with CL [28]. This may be because FC is particularly effective in practice-oriented subjects (e.g., pharmaceutical calculation and anesthesia crisis management) but not in abstract and memorization-heavy subjects, such as ophthalmology and neuroanatomy [21]. Further research is needed to identify the types of subjects and assessment methods that can maximize the benefits of the FC approach.

An interesting finding in our study is that no significant difference in 'Situation awareness' was found between the FC and CL groups, while significantly more participants in the FC group could recognize the acute pulmonary embolism and take the correct treatment measure, as evaluated by the simulation instructor. This discrepancy may be attributed to two factors: firstly, the ANTS system rates 'Situation awareness' in three aspects, including gathering information, recognizing and understanding, and anticipating [25]. While some participants may diagnose pulmonary embolism correctly based on their knowledge, their information gathering abilities may not be directly improved through our training process. Secondly, the raters assessed the performance of the participants based on video recordings and may miss more details compared with the on-site instructor, which may have introduced some biases in their ratings.

Study load in FC is another issue that needs to be highlighted by medical educators. Previous studies showed that some students were unhappy with being asked to work at home and unwilling to take another FC [20], citing the additional time required to complete the pre-class work [31]. It should be emphasized that successful completion of the FC requires students' participation and cooperation [32, 33], since students being asked to do more self-learning could resist the idea. Well-developed pre-class materials are one of the critical elements that may mitigate this problem. Firstly, the instructors must consider limiting the total combined length of video segments. In our course, the online pre-class video was limited to 20 min, which was acceptable to most learners. Secondly, the teachers need to plan the course content carefully to avoid prolonged self-learning in a single format. In the present study, the learning objectives were simplified and divided into three parts and previewed via various learning approaches, including video lectures, assigned reading materials, preparation for in-class presentations and discussions. Although the students in the FC group spent longer time pre-class, they performed better in the simulation and post-training test without spending extra total time.

This study has several strengths. Firstly, our course was well designed by combining the FC with the anesthesia crisis management simulation course, with a focus on perioperative pulmonary embolism management. FC can encourage the students to preview the simulation comprehensively before the training session, which resulted in improved learning outcomes. Secondly, to the best of our knowledge, this study is the first to employ FC in anesthetic crisis management simulation. We have utilized a comprehensive set of metrics, including theoretical exams, ANTS rating system, and observational items to evaluate students' performance, which may inspire future studies in other medical education modules. However, this study is not without limitations. Firstly, we employed a quasi-experimental study design, which may limit the demonstration of a direct association between intervention and outcome. Secondly, we only evaluated the students' performance in a simulated acute pulmonary embolism case rather than many different types of emergencies. Further investigations with various cases are required. Thirdly, we employed a convenient sampling approach to recruit residents from a single center, which may have led to biases in the results. Future studies involving more participants from different centers may further validate the effectiveness of FC in anesthesia crisis management training. Fourthly, the self-reported time spent by the students on learning-related activities may be inaccurate. In addition, assessment after the video will play a key role in the success of FC, we failed to tailor the assessment after FC, as we intend to uniform the assessment procedure, which may lower the actual performance of FC. Last but not least, we did not take measures to prevent communication between the two groups. As a result, we could not rule out the potential influence of internal inferences, as participants in the FC group may have shared their knowledge or experience with those in the CL group through extracurricular interactions, which may have led to biases in the results. Future studies should consider strategies to minimize cross-group communication, such as scheduling training sessions at separate times.

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Author contributions
Yun Wang: Literature review, methodology development, data analysis and interpretation, manuscript writing. Tian Hong: Course design review, research quality control, manuscript editing and revision. Jianyun Li: Data collection and processing, analysis, and interpretation. Chongzhi Zhou: Scientific advising, processing. Yiwen Feng: Manuscript editing and revision. Corresponding author: Lina Huang: Methodology development, study implementation, data analysis and interpretation, manuscript writing. Co-corresponding author: Jinbao Li: Conceptualization and study design. Supervised the project.

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Data availability
No datasets were generated or analysed during the current study.

Declarations

Ethics approval and consent to participate
The study was approved by the Medical Ethics Committee of Shanghai General Hospital (Approval No. 2022KY136). All participants signed informed consent.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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