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Application of AI-assisted multi-advisor system combined with BOPPPS teaching model in clinical pharmacy education

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Abstract

Background The development of clinical pharmacy in China has been relatively slow, and standardized, effective training for clinical pharmacists remains a major challenge. At present, traditional teaching methods are not conducive to cultivating clinical practice abilities or critical thinking, leading to a lack of enthusiasm among students. To address this issue, a hybrid teaching model combining an AI-assisted multi-advisor system with the BOPPPS (bridge, objective, pre-assessment, participatory learning, post-assessment, summary) teaching method was applied in clinical pharmacy education.

Methods In this study, a teaching model was developed that consists of five components: advisor system, teaching strategy, teaching method, teaching mode, and assessment methods. The model was implemented in the Pharmacy Department of Xiangya Hospital at Central South University in Changsha, China, from spring 2023 to spring 2024. After the spring 2024 training session, anonymous questionnaires were completed by students. The effects of the teaching reform were evaluated. The questionnaire focused on clinical practice effectiveness, course design rationality, improvement in professional ability, interest in learning, and perceptions of ChatGPT as a teaching tool.

Results A total of 81 students participated in the study, with 69 completing the questionnaire survey (response rate: 85.2%, $n=69$). Overall, students gave positive comments regarding the instructional improvements. A higher proportion of interns and advanced students considered the courses difficult (32.4%, $n=12$ and 31.6%, $n=6$, respectively). Identified shortcomings include the frequent periodic assessments and increased pressure. Regarding the use of ChatGPT, 49 students (71.0%, $n=49$) commented that it played a multidimensional role in teaching. The most valued asset was its ability to provide massive data information (43.5%, $n=30$), while the lack of interactivity was a prominent issue (56.5%, $n=39$).

Conclusion This innovative teaching model integrating an AI-assisted BOPPPS framework with a supervised ChatGPT implementation may facilitate the comprehensive self-evaluation of abilities. This research offers a replicable model for AI-driven educational transformation in clinical pharmacy training.

Keywords ChatGPT, BOPPPS, Clinical pharmacy education, Critical thinking, Clinical practice skills

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Introduction

The 1910 Flexner Report revolutionized medical education by emphasizing laboratory science and biomedical research, contributing to significant advancements in medicine and an increased life expectancy. However, its narrow focus on basic science has proven inadequate for addressing modern healthcare challenges, which demand a stronger emphasis on compassionate care and leadership skills. Today's complex healthcare system requires physicians trained not only in scientific rigor but also in strategic thinking, teamwork, and quality improvement. A more balanced approach integrating science with leadership and humanistic values is essential for future medical education [1]. Modern medical education theory emphasizes the critical importance of integrating theoretical knowledge with clinical practice through experiential learning [2]. The cognitive apprenticeship model highlights how learners develop expertise through guided participation in authentic clinical activities under supervision [3]. However, effective implementation requires adequate faculty support and structured pedagogical approaches that progressively develop clinical reasoning skills [4]. These theoretical foundations are particularly relevant for clinical pharmacy education, in which medication management decisions directly impact patient outcomes.

Despite advancements in pharmaceutical education, China's clinical pharmacy training lags behind Western and Asian counterparts due to late disciplinary development and a theory–practice gap [5–7]. Current curricula emphasize theoretical knowledge in the early years, delaying clinical exposure until the fourth/fifth year and hindering practical applications [8]. While the demand for clinical pharmacists grows [9, 10], the traditional single-advisor model suffers from monotonous content, faculty shortages, and overburdened preceptors [11, 12], limiting students'clinical reasoning and critical thinking development [13]. Surveys indicate pharmacists often lack comprehensive skills and face communication barriers [14].

To address these challenges, an AI-assisted multi-advisor system was integrated with the BOPPPS model (Bridge, Objective, Pre-assessment, Participatory learning, Post-assessment, Summary) [15]. AI tools (e.g., ChatGPT, Deepseek, KIMI, Doubao) offer personalized learning, real-time feedback, and workload reduction while improving accessibility. Potential risks include data privacy, AI overreliance, and content accuracy, requiring safeguards. Clinical pharmacist for kidney transplantation were used as the test case. Complex specialties like kidney transplantation require expertise in therapeutic drug monitoring and perioperative care [16, 17], yet China's education system struggles to deliver such training effectively. This study aims to improve students'clinical practice abilities across different dimensions by fostering critical thinking and enhancing enthusiasm for learning.

Methods

Setting and development of the program

Xiangya Hospital at Central South University in Changsha City, China, is a large, comprehensive tertiary teaching hospital. Each year, approximately 60–100 students from various schools and hospitals engage in advanced studies in the Pharmacy Department. Based on past teaching experiences and problems that existed in the department's teaching center, the teaching approach was improved across the following five dimensions: advisor system, teaching strategy, teaching method, teaching mode, and assessment methods, as shown in Table 1. The objectives of improved teaching approach were improving accuracy in medication decision-making within simulated clinical scenarios, fostering collaborative problem-solving skills through structured interactions with AI-aided mentors, promoting self-directed learning via the BOPPPS framework's phased approach. therapeutic decision-making, interdisciplinary communication, and adaptive learning ability, and enhancement of objective structured clinical examination (OSCE) scores.

This educational reform was proposed in 2022 and applied in the Pharmacy Department of the hospital from spring 2023 to spring 2024. The project was approved by

Table 1 Comparison between traditional teaching and improved teaching methods

	Traditional teaching	Improved teaching
Advisor system	Single advisor system	Multi-advisor system
Teaching strategy	Clinical pharmacy course + clinical practice	Clinical pharmacy course + TDM practice + Genetic testing practice + clinical practice
Teaching method	Teacher-student interactive teaching	Teacher-student interactive teaching + AI-assisted teaching
Teaching mode	Teacher-directed knowledge dissemination	Students engaged BOPPPS teaching
Assessment methods	Traditional final examination	Periodic assessment + OSCE

the ethics committee of Xiangya Hospital, Central South University (No.202311223), and informed consent was obtained from all study participants.

The educational system is structured as follows: interns and specialized clinical pharmacists are enrolled in a one-year program, while graduate students are enrolled in a two-year program (i.e., the second and third year of study). The learning process is divided into five stages: clinical pharmacy course (first week), laboratory admission and therapeutic drug monitoring (TDM) (second and third week), genetic testing (fourth and fifth week), and clinical pharmacy practice (sixth week). This framework forms a bridge between the theoretical course and clinical practice. The Clinical Pharmacy Group, TDM Laboratory, and Genetic Testing Laboratory all belong to the pharmacy department, which facilitates and enhances teaching work. Prior to their studies, each group of students must participate in a one-week theoretical course training. The specific teaching content can be found in Supporting Information Table S1.

Constructing a multi-advisor system

As part of the reform, multiple types of educators were recruited from the hospital to teach the various components involved in pharmacist education, including two TDM advisors, two genetic testing advisors, three clinical pharmacists, and two physicians. Team members clearly defined their respective teaching responsibilities and held two meetings, one mid-semester and one at the end, to review and summarize their teaching activities.

TDM advisors

TDM is an important tool for determining drug exposure in patients and creating individualized medication regimens based on the drug treatment window. TDM instructors at the hospital are teachers with intermediate and higher academic titles, and the teaching content during the research period includes theoretical teaching, on-site practice, and application-based teaching.

The theoretical teaching content includes topics such as biosafety, an overview of TDM, and TDM technologies. On-site practice includes techniques such as high-performance liquid chromatography (HPLC), high-performance liquid chromatography mass spectrometry (HPLC–MS), and enzyme-linked immunoassay, all of which are widely used in hospitals. The most important aspect of TDM instruction is application-based teaching, which involves the interpretation of TDM reports, case analysis, and TDM research.

The learning cycle for TDM instruction lasts two weeks. Interpreting TDM results and formulating individualized treatment plans are important aspects of clinical practice. TDM training carried out in the laboratory focused on common antibiotics such as vancomycin and voriconazole, anti-epileptic drugs such as valproic acid and carbamazepine, and immunosuppressants such as tacrolimus, cyclosporine, sirolimus, and mycophenolate acids.

Genetic testing advisors

Pharmacogenomics examines the relationship between gene sequence polymorphisms, pharmacokinetics, and pharmacodynamics, making it an important part of evidence-based precision medicine [18]. The pharmacologist responsible for drug gene testing is a doctor of pharmacology, and the teaching outline for this two week-long training session is the same as the TDM course.

Theoretical lectures by pharmacists address biosafety, drug genetic testing, and testing principles. The application-based teaching involves interpreting drug gene test reports, analyzing cases, and conducting research based on pharmacogenomics. Some commonly used drugs, such as tacrolimus and cyclosporine, which are frequently prescribed to transplant patients, require genetic testing as they are mainly metabolized by liver drug enzymes P450 3A4 and 3A5. Based on tacrolimus drug gene testing and TDM interpretation, students create individualized patient plans, translating abstract data into clinical recommendations. This process enables students to gain a deep understanding of this foundational knowledge and apply it to clinical practice, generating both self-confidence and a sense of accomplishment.

Clinical pharmacist advisors

After completing the theoretical study and therapeutic drug monitoring stages, students are mainly taught by clinical pharmacists and physicians. The main educators for clinical practice are usually clinical pharmacists with at least three years of experience and a teaching certificate. They are responsible for guiding students in various aspects of drug therapy management for patients. Specifically, they teach students how to evaluate treatment programs, prescribe medication, record and handle adverse reactions, communicate with medical staff and patients, and retrieve relevant literature. In addition, clinical pharmacists also assess students'teaching effectiveness and may provide guidance on some students' theses.

Physicians advisors

Clinician instructors must be attending physicians who have been engaged in clinical work for over three years. They are responsible for teaching the diagnosis and treatment of common diseases and providing medical information to trainees.

Combining AI with BOPPPS Teaching

AI-assisted provision of learning resources

When students enter the clinical practice, it is important to cultivate their ability to solve problems by consulting data. As a large language model (LLM) and artificial intelligence (AI) chatbot, ChatGPT is receiving increasing attention in the medical field due to its excellent ability to access and summarize large amounts of information. However, it is important to highlight that this platform may also provide false medical information [19, 20]. While traditional teaching practice involves directly teaching content to students or providing learning materials, in this study ChatGPT was used to improve students'ability to retrieve and critique information. One teaching approach used with participants involved prompts with ChatGPT. The instructor selected at teaching topic [e.g.,"How to manage blood sugar after kidney transplantation?"]. Students first asked ChatGPT to generate an answer and then used other methods to verify the answer (see"Literature Retrieval and Literature Reading Report"in the theoretical class). They integrated the two answers into a final answer, which the teaching pharmacist judged. The latter also determined the appropriateness of the references that students used to formulate the response. This approach, specifically, teaching with ChatGPT, encourages self-directed learning, which typically helps motivate students to complete tasks [21]. The act of seeking and critiquing information is an important practice, but also an important means for assessing students' critical thinking skills.

AI-assisted BOPPPS teaching

Approximately one month after starting their work in the clinic, when the students were familiar with clinical pharmacy work, ChatGPT was invited to participate in the teaching session as a"competitor". The pharmacist selected clinical patients according to teaching objectives and reorganized the patients'conditions as BOPPPS teaching cases. When there were no suitable patients at present, the cases were selected from a question bank. The learning was carried out in groups. An example of the BOPPPS teaching approach, using newly diagnosed diabetes mellitus (PTDM) after kidney transplantation, is shown in Table 2. The specific operation process for ChatGPT involved recording the patient's anonymized personalized medical diagnosis data, including detailed medical records, laboratory test results, and even genetic test reports, to obtain the ChatGPT's series of possible clinical medication protocols, including precise dosage and number of medication precautions.

AI-assisted drug education

Communication skills and medication education represent the practical application and enhancement of theoretical knowledge and are key components of clinical practice. Kidney transplant patients often face problems such as drug management, drug interactions, and precautions, so medication education for such patients before discharge can significantly reduce the error rate after discharge [22, 23]. As part of the activities during clinical practice, students reviewed and modified the proposal by ChatGPT, and the teacher verified and modified their work. The student then conducted a medication education session with the patient, accompanied and guided by the clinical pharmacist.

Student assessment methods

Based on simulated clinical situations, the Objective Structured Clinical Examination (OSCE) system allows for multi-dimensional, comprehensive assessment of students'clinical judgment, processing and communication abilities, knowledge, and attitudes [24]. It provides timely teaching feedback, helping to identify students' weak areas in clinical practice and evaluating clinical thinking and practice abilities. At the same time, the improved assessment model integrates phased assessments to measure students' understanding and mastery of the material at each stage. This model can help students adjust their learning approaches, while enabling teachers to refine their pace, intensity, and methods.

Program assessment

In order to evaluate the improved teaching approach, a questionnaire covering 27 items was designed. The questionnaire was evaluated by three clinical pharmacy advisors and two AI-in-education specialists to confirm content validity. Revisions were made based on their feedback. It uses a five-point Likert scale (1 =strongly disagree; 2= disagree; 3= neither agree nor disagree; 4= agree; 5= strongly agree) to evaluate students'perceptions of clinical practice teaching effectiveness, the design of the theoretical course, the development of their professional abilities, and learning interest. Open-ended questions ask students how they feel about the improved teaching approach, prompting them to share its advantages and disadvantages in order to identify problems. Four semi-open-ended questions focus on students'perceptions of AI-assisted instruction. Questionnaires were sent out after the training through a tool called Questionnaire Stars, and students were asked to complete them anonymously. Table S2 in Supporting Information shows the content of the questionnaire. The validity and reliability of the questionnaire were as follows. The Kaiser–Meyer–Olkin sampling adequacy

Table 2 Application of the BOPPPS teaching model using post-transplantation diabetes mellitus (PTDM) as an example

Steps	Teaching and Learning Design
Pre-class	In this course, students will explore the medication therapy management of PTDM through a structured approach that integrates case study analysis and the use of ChatGPT to determine the appropriateness of learning materials
Bridge-in	(1) A case study involving PTDM patient will be conducted in the clinical practice. This case will introduce the issue of medication therapy management in PTDM. Students will be prompted to discuss key questions, such as:"How does the treatment of PTDM differ from that of diabetes mellitus?"This discussion will help highlight the specific challenges and the role of clinical pharmacy services in managing PTDM (2) If an appropriate case related to the teaching theme is unavailable during the course, a substitute case will be selected from the case collection to ensure continuity in learning
Objective	(1)Knowledge objectives: Students will gain a comprehensive understanding of the diagnosis and treatment of PTDM. This includes understanding the risk factors associated with PTDM, as well as the pharmacological effects, dosing regimens, and adverse effects of hypoglycemic medications (2)Skills objectives: Through the study of PTDM, students will develop the ability to propose initial medication therapy management strategies for patients with PTDM (3)Attitudinal objectives: By exploring the adverse prognostic implications of PTDM in transplant patients, students will gain an appreciation for the importance of PTDM, motivating them to engage with clinical pharmacy practice
Pre-test	Guiding Questions and Discussion Prompts: To facilitate learning and critical thinking, the following questions will guide student discussions: • What is the incidence of PTDM? • How is PTDM diagnosed, and what are the key treatment strategies and principles? • What is the appropriate approach for screening and monitoring patients during the postoperative period? • What are the therapeutic goals for managing PTDM? • How does perioperative glycemic management differ from long-term postoperative glycemic control? • What pharmacological treatments are currently available for PTDM?
Participatory learning	The primary teaching method will involve students working in groups, supported by ChatGPT, to develop hypoglycemic drug treatment plans and medication therapy management for the patient in the case study. The instructor will guide the groups to critically assess their proposed plans, comparing their ideas with the solutions generated by ChatGPT, addressing any errors or gaps in knowledge, and reinforcing key concepts through targeted feedback
Post-test	To assess the effectiveness of the learning process, quizzes will be published through questionnaire. These quizzes will help evaluate students'understanding and retention of the material
Summary	(1)Mind Mapping of PDTM: Students will work in small groups to summarize key information related to PDTM using mind mapping techniques. This collaborative exercise aims to enhance understanding by visually organizing complex concepts and relationships (2)Case Analysis: Students will be required to write a comprehensive case analysis of a patient diagnosed with PTDM. This task encourages critical thinking and application of theoretical knowledge to real-world clinical practice

measure was 0.809 and the Bartlett's test of sphericity was significant with a p value of < 0.001. The global Cronbach α of the questionnaire was 0.860.

Data collection

After the spring training in 2024, the anonymous survey questionnaires were distributed to 81 students (44 interns, 14 postgraduates, and 23 advanced students). The advanced students group included those students who had work experience but were seeking additional professional knowledge. A total of 69 valid questionnaires were collected, with a response rate of 85.2%. The study population was comprised of 31 pharmacy students, six clinical pharmacy students, and 32 students from other pharmaceutical sciences programs (including pharmaceutical engineering and Chinese medicine). When sorted by group, the population included 37 interns, 13 postgraduates, and 19 advanced students. Some students, which may have included short-term learners, did not fill out the questionnaire as required.

Data analyses

SPSS 26.0 was used for data analysis. After the training, students'ratings on different teaching dimensions and their perceptions of AI-assisted teaching were summarized using frequency. An exploratory factor analysis was conducted using principal component analysis with Varimax rotation to examine the factor structure of the 17 items in the questionnaire. The reliability of the questionnaire was measured using Cronbach alpha coefficient. The Kruskal Wallis rank sum test was used to compare answers to the same questions across different groups and majors, as the data was not normally distributed. The differences in propensity scores are described by median. Statistical tests were 2-tailed, and $P < 0.05$ was considered statistically significant. To quantify the clinical and practical significance of the attitudinal differences between the three groups, this study employed epsilon-squared (η^2_H), a nonparametric effect size measure derived from the Kruskal–Wallis H-test. The calculation of η^2H was based on the H-statistic, adjusted for the number of groups and the sample size: η^2_H = [H- (k-1)]/N-k.

H represents the Kruskal–Wallis test statistic, k is the number of groups (k = 3 in this study), and N is the total sample size. For statistically significant results ($P < 0.05$), the 95% confidence interval (CI) of η^2_H was further estimated using 10,000 Bootstrap samples to assess the precision of the effect size. Open-ended comments were analyzed using traditional content analysis [25, 26].

Results

Students' evaluation of teaching effectiveness during clinical practice

In questions six to ten, students were asked to score the effectiveness of the improved multi-advisor system, teaching plan, teaching method, BOPPPS teaching model, and assessment methods. A higher score indicates a preference towards the improved teaching approach. The survey results (Fig. 1A) show that students generally gave positive evaluations of the teaching improvements.

The questionnaire data for different student groups and majors are shown in Fig. 1. There were no significant differences in the preferences for the improved teaching approach between students from different majors. The assessment scores revealed that postgraduates did not prefer the new assessment method (the median assessment score was 3), while there was no statistical difference when compared with the other two groups ($P > 0.05$). Further analysis demonstrated distinct preference patterns between postgraduates and advanced students. The strongly disagree/disagree option was selected most frequently by postgraduates (highest percentage, 30.8%, $n = 4$) but least frequently by advanced students (lowest percentage, 10.5%, $n = 2$). Conversely, the strongly agree/agree option showed the opposite trend, with the lowest selection rate among postgraduates (30.8%, $n = 4$) and the highest among advanced students (63.2%, $n = 12$).

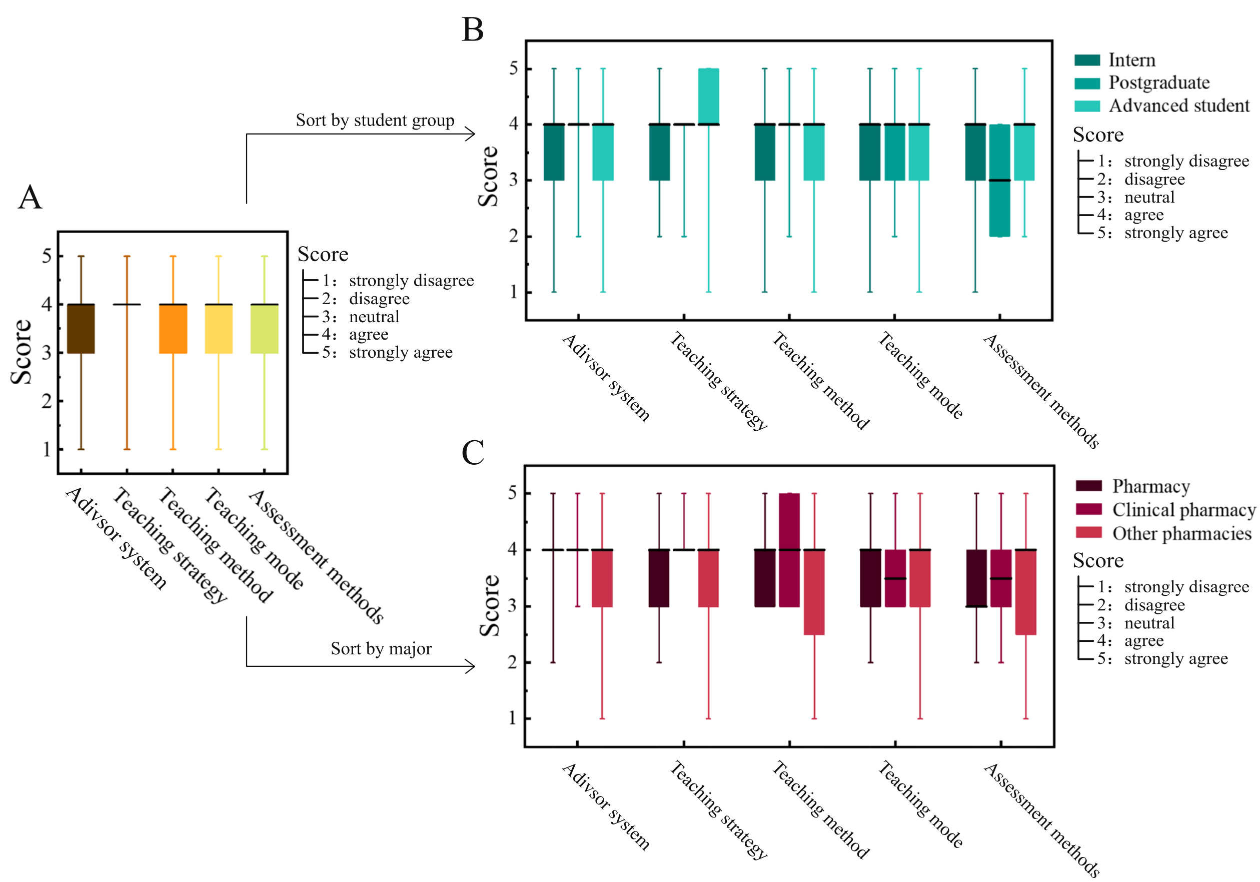

Fig. 1 Students'evaluations of teaching effectiveness. **A** Students'evaluations of teaching effectiveness ($N = 69$); **B** Evaluation of teaching effectiveness by different student groups (Interns = 37, Postgraduate = 13, Advanced student = 19); **C** Evaluation of teaching effectiveness by students from different majors (Pharmacy = 37, Clinical pharmacy = 6, other pharmacies = 32). The data were assessed for normality, and comparisons were conducted using the Kruskal–Wallis rank-sum test due to the non-parametric distribution. Data are presented for the median and interquartile range (IQR), with the boxplot elements defined as follows: the solid black line represents the median, the box spans the IQR (25 th–75 th percentiles), and the vertical whiskers extend to the full data range. Responses were recorded on a five-point Likert scale, where 1 corresponds to"strongly disagree"and 5 denotes"strongly agree"

The results from the semi open-ended questions are shown in Table 3. Most students expressed that their interest in learning was stimulated, and that their comprehensive abilities, clinical expertise, and clinical experience were fully engaged. The learning atmosphere was more relaxed. In terms of shortcomings, some students noted that the frequent periodic assessments increased assessment pressure. Although the original intent of the assessment method was to help teachers understand students'learning progress, two students saw this as a positive feedback mechanism. Additionally, students also believed that the existing teaching syllabus lacked sufficient structure, requiring students to take more time to adapt to the new teaching format.

The study found that some students were learning about ChatGPT and OSCE for the first time, while others had already used these tools during their undergraduate studies. In addition, although some students appreciated the free learning atmosphere, others felt that the"human–machine hybrid"teaching method lacked sufficient constraints, leading to laziness and lack of timely interaction from instructors. The issue of team collaboration mainly manifested in two ways: firstly, differences in the content taught by different advisors, and second, the varying levels of familiarity that advisors had with individual students.

Students' evaluation of the course design

As shown in Fig. 2A, only one advanced pharmacy student thought that the theoretical courses were overscheduled. Meanwhile, 38 students (55.1%, $n=$ 38) thought that the difficulty and quantity of the courses were moderate, and 18 students (26.1%) found the theoretical courses difficult. Evaluations of the theoretical courses differed greatly among different student groups. The proportion of interns (32.4%, $n=$ 12) and advanced students (31.6%, $n=$ 6) who thought the courses difficult was higher. The questioning and feedback session after class revealed that the interns were unfamiliar with the curriculum contents of the hospital pharmacy training. The advanced students struggled to absorb more clinical practice knowledge, although they thought the courses would be very helpful for their future work. A similar trend was observed among students of different majors. Compared to clinical pharmacy students, those majoring in pharmacy (22.6%, $n=$ 7) and other fields (31.2%, $n=$ 10) reported a higher proportion of difficulty with the course arrangements.

The assessment results indicate that students positively evaluated the theoretical courses, TDM courses, and genetic testing courses (see Fig. 2C and D). They felt that the course arrangements were beneficial to understanding clinical pharmacy work and integrating it effectively within clinical practice. No significant differences were observed among different student groups; however, varied opinions were observed among students across different majors. The results of a Kruskal–Wallis test revealed a significant difference in the attitudes toward the TDM courses among the three major groups (H $=6.322$, $p=$ 0.042), with an effect size of η^2_H $=0.065$ [95% CI: 0.002, 0.175], indicating a small to medium effect. Clinical pharmacy students were more likely to value TDM courses than the other students (median score 4.5 vs. 4, $P=$ 0.040).

Students' self-evaluations of skill development

In general, assessment results provide a direct measure for evaluating training effectiveness. However, since the subjects of this survey are the first batch of students to experience the improved teaching methods, and they have been exposed to new teaching and assessment content, it is not possible to directly compare the results with

Table 3 Advantages and disadvantages perceived by students related to the teaching reform

Advantages	N (%)	Disadvantages	N (%)
Stimulates interest in learning	20(29.0)	The syllabus lacks sufficient systematization	7(10.1)
Enhances comprehensive abilities	17(24.6)	Requires time for students to acclimate	6(8.7)
Expands clinical expertise	8(11.6)	Limited timely interaction from instructors	6(8.7)
Fosters critical thinking and broadens perspectives	6(8.7)	Self-study may reduce student discipline	6(8.7)
Facilitates easier comprehension and understanding	5(7.2)	Potential for distractions	2(2.9)
Encourages relaxed atmosphere in learning	5(7.2)	Absence of post-class review materials, such as videos	2(2.9)
Provides valuable clinical practice experience	4(5.8)	High pressure associated with assessments	2(2.9)
Promotes high interactivity and engagement	3(4.3)	Team-related issues may arise	2(2.9)
Enables timely and constructive teaching feedback	2(2.9)	Increased learning tasks	3(4.3)
		Tendency to develop inertia	2(2.9)
		Elevated learning costs	1(1.4)

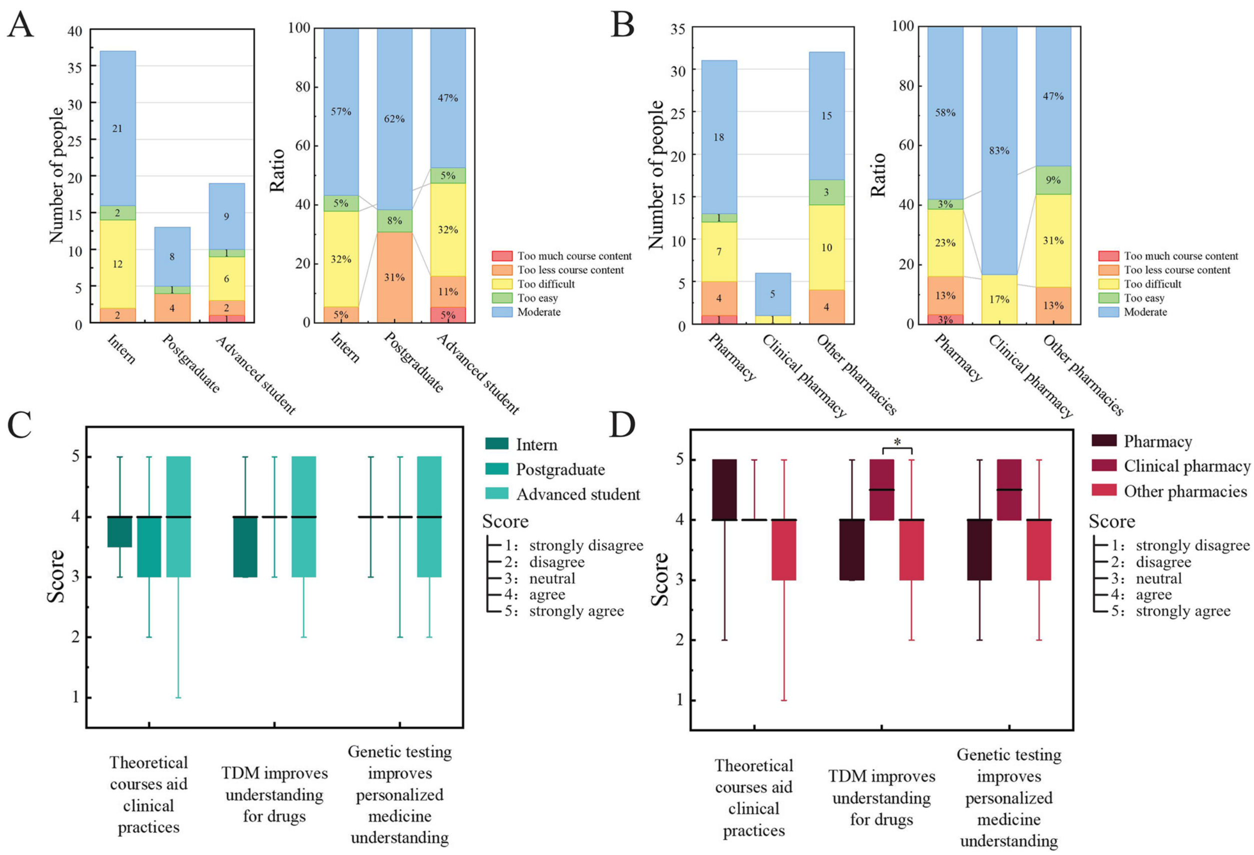

Fig. 2 Students'evaluations of theoretical courses. **A** Evaluation of theoretical courses by different student groups (Interns = 37, Postgraduate = 13, Advanced student = 19); **B** Evaluation of theoretical courses by students from different majors (Pharmacy = 37, Clinical pharmacy = 6, other pharmacies = 32); **C** Evaluation of course arrangements by different student groups; **D** Evaluation of course arrangements by students from different majors. Data of 2 C and 2D are presented for the median and interquartile range (IQR), with the boxplot elements defined as follows: the solid black line represents the median, the box spans the IQR (25 th–75 th percentiles), and the vertical whiskers extend to the full data range. Responses were recorded on a five-point Likert scale, where 1 corresponds to"strongly disagree"and 5 denotes"strongly agree"

those of past students. To solve this problem, students were encouraged to evaluate their own improvements in areas such as professional theory, clinical thinking, and communication skills. As shown in Fig. 3, students generally believed that their professional abilities were improved after the training.

Evaluation of the impact on student engagement

The improved teaching format included multiple advisors, exposing students to a variety of clinical thinking and working methods, while also incorporating more flexible teaching tools. The results showed students were more focused and less tired during the learning process (Fig. 4).

Evaluation of chatGPT as a teaching tool

ChatGPT was introduced into this study as a tool to cultivate critical thinking. As demonstrated in Fig. 5, students from different groups and majors gave positive evaluations on its role as a learning device. Some advanced students said that they had learned about and applied ChatGPT for the first time. Overall, 49 students (71.0%, n = 49) believed that ChatGPT played a positive role in teaching to varying extents, while 20 students (29.0%, n = 20) remained undecided.

As a generative AI tool, ChatGPT provides massive amounts of information by entering keywords or summaries, greatly facilitating students in finding the knowledge they require. This advantage was recognized by most students (43.5%, n = 30). Another 25 students (36.2%, n = 25) thought that ChatGPT was useful for helping them understand complex problems. While 36 students (52.2%, n = 36) believed that ChatGPT could replace teachers in some aspects, 16 students (23.2%, n = 16) disagreed. The most common problem reported by students when using ChatGPT was a lack of interactivity (56.5%, n = 39). Among students from different majors, clinical pharmacy students were more troubled by the wrong answers

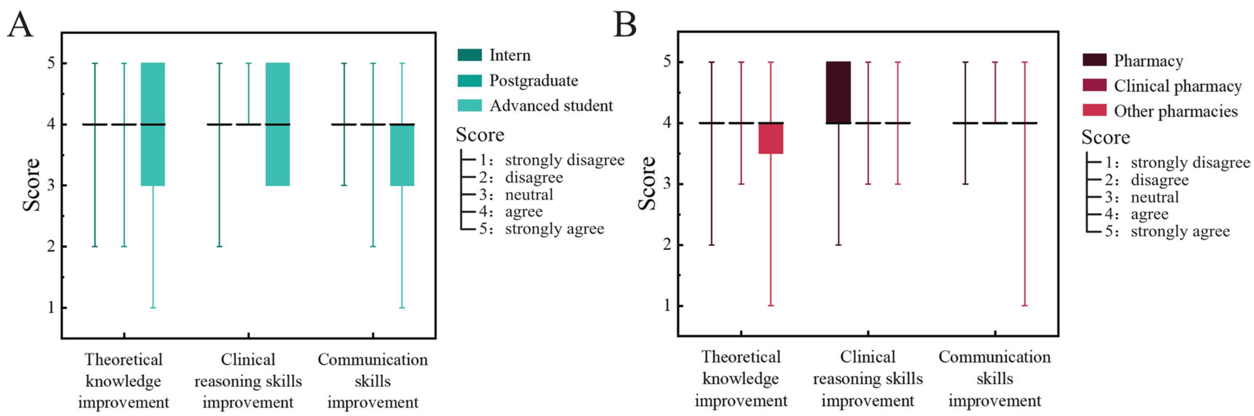

Fig. 3 Students'self-evaluation of skills development. **A** Self-evaluation of skills development by different student groups (Interns = 37, Postgraduate = 13, Advanced student = 19); **B** Self-evaluation of skills development by students from different majors (Pharmacy = 37, Clinical pharmacy = 6, other pharmacies = 32). The data were assessed for normality, and comparisons were conducted using the Kruskal–Wallis rank-sum test due to the non-parametric distribution. Data are presented for the median and interquartile range (IQR), with the boxplot elements defined as follows: the solid black line represents the median, the box spans the IQR (25 th–75 th percentiles), and the vertical whiskers extend to the full data range. Responses were recorded on a five-point Likert scale, where 1 corresponds to"strongly disagree"and 5 denotes"strongly agree"

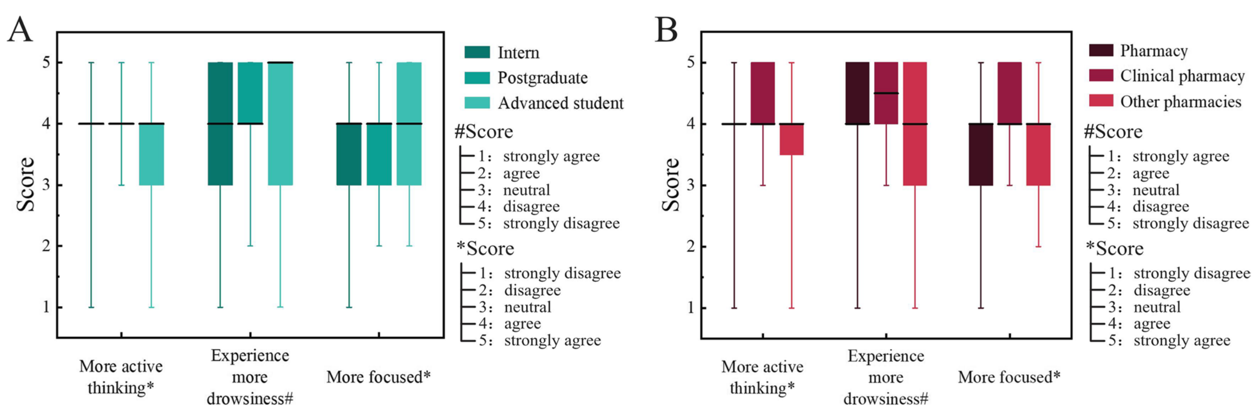

Fig. 4 Evaluation of the impact on student engagement. **A** Evaluation of learning interests by different student groups (Interns = 37, Postgraduate = 13, Advanced student = 19); **B** Evaluation of learning interests by students from different majors (Pharmacy = 37, Clinical pharmacy = 6, other pharmacies = 32). The data were assessed for normality, and comparisons were conducted using the Kruskal–Wallis rank-sum test due to the non-parametric distribution. Data are presented for the median and interquartile range (IQR), with the boxplot elements defined as follows: the solid black line represents the median, the box spans the IQR (25 th–75 th percentiles), and the vertical whiskers extend to the full data range. Responses were recorded on a five-point Likert scale.* 1 corresponds to"strongly disagree"and 5 denotes"strongly agree". # 1 corresponds to"strongly agree"and 5 denotes"strongly disagree"

provided by ChatGPT (66.7%, $n = 4$), while students from pharmacy (51.6%, $n = 16$) and other majors (65.6%, $n = 21$) reported difficulties with the lack of interaction.

Discussion

In this study, survey results showed generally positive perceptions of the teaching model, though with group variations. Interns and advanced students found the courses more challenging, while postgraduates valued TDM more. Most students recognized ChatGPT's educational utility, with nearly half of the students highlighting its data synthesis capabilities. However, more than half of students cited limited interactivity as a key drawback. A few raised concerns about team-related issues with advisors. Findings highlight both the potential and the limitations of AI-assisted learning across diverse student groups. As this study was the first attempt made by the researchers to use an AI-assisted, multi-advisor system combined with the BOPPPS teaching model, it was anticipated that the change of teaching methods would bring a series of unpredictable difficulties. Indeed, some problems were identified after the training. The results

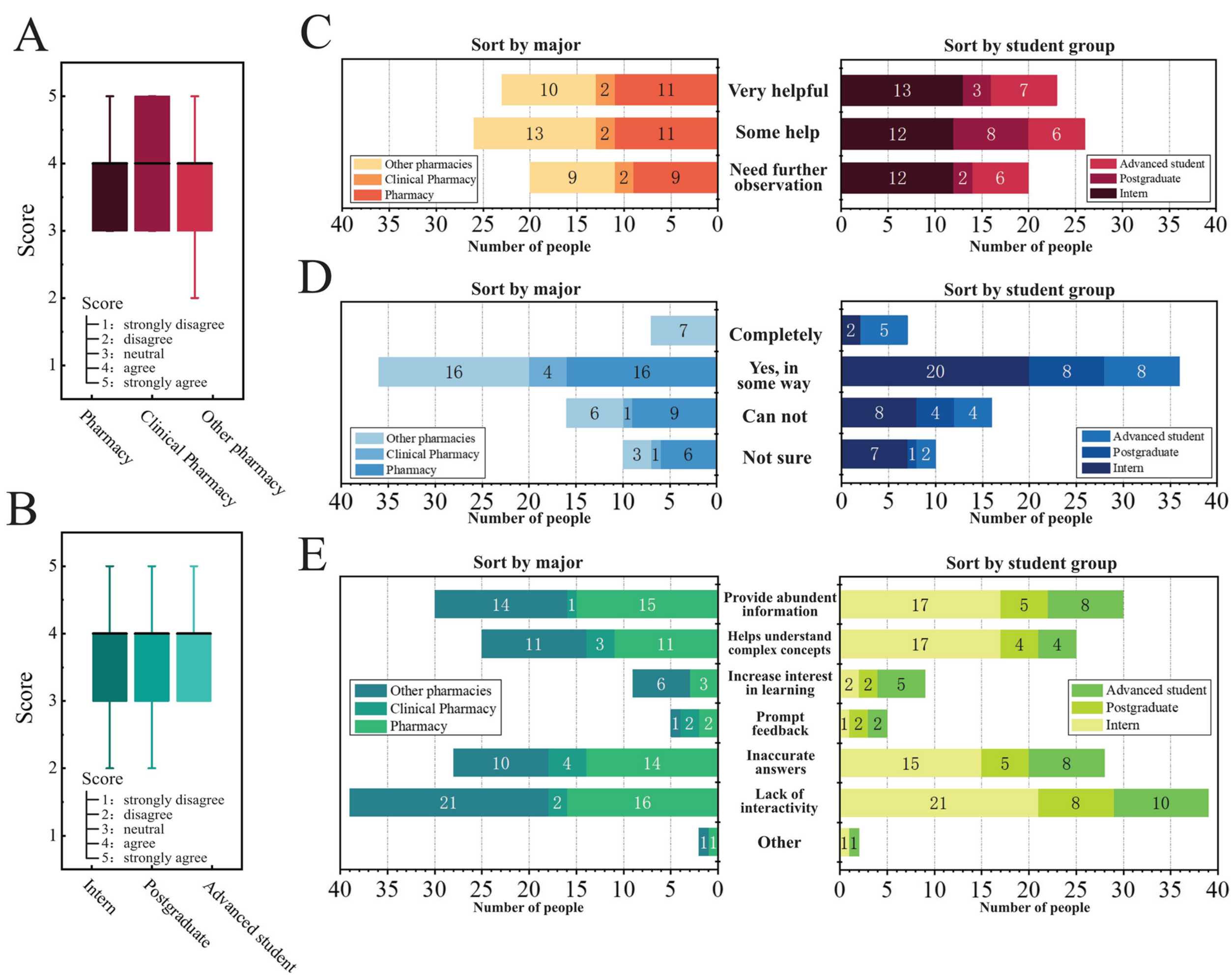

Fig. 5 Evaluation of ChatGPT as a teaching tool. **A** Self-evaluation of ChatGPT's role in enhancing critical thinking by students from different majors (Pharmacy = 37, Clinical pharmacy = 6, other pharmacies = 32); **B** Self-evaluation of ChatGPT's ability to enhance critical thinking across different student groups (Interns = 37, Postgraduate = 13, Advanced student = 19); **C** Students'evaluation on ChatGPT's role in teaching; **D** Students'evaluation on the importance of ChatGPT and teachers; **E** The advantages and disadvantages of ChatGPT identified by students. Data of 5 A and 5B are presented for the median and interquartile range (IQR), with the boxplot elements defined as follows: the solid black line represents the median, the box spans the IQR (25 th–75 th percentiles), and the vertical whiskers extend to the full data range. Responses were recorded on a five-point Likert scale, where 1 corresponds to"strongly disagree"and 5 denotes"strongly agree"

showed that students from different groups and majors possessed different feelings on theoretical and practical courses and on assessment methods.

Differences emerged in students'perceptions of curriculum difficulty and the importance of TDM courses across the different major groups. Pharmacy students and those from other fields reported greater challenges with the curriculum and assigned lower priority to TDM courses compared to clinical pharmacy students. This disparity primarily stems from fundamental differences in curricular structure across disciplines. Clinical pharmacy systematically integrates TDM principles throughout its vertically-structured curriculum [5, 27, 28], combining pharmacotherapeutics, clinical pharmacokinetics, and hands-on hospital training where students apply TDM concepts to optimize drug regimens (e.g., valproic acid) [29, 30]. This immersive approach fosters greater familiarity with TDM's clinical role, whereas other majors often treat TDM as an isolated topic. Despite the perceived difficulty, maintaining rigorous TDM training remains essential, as healthcare professionals across disciplines recognize its clinical value and pharmacists'critical role in interpreting TDM data [31]. The findings suggest curriculum structure significantly influences students'perceptions and preparedness for clinical decision making involving TDM.

This study also revealed a divergence in perceptions of the assessment method between graduate and advanced students. While advanced students responded favorably, postgraduates showed significantly lower acceptance, likely due to: (1) advanced students'prior exposure to similar assessment formats and (2) varying perceptions of assessment relevance at different academic stages. The new method combined continuous and final assessments to evaluate learning across training sections, encouraging students to address knowledge gaps [32, 33]. However, graduate students faced greater challenges balancing these additional assessments with clinical duties and coursework. The OSCE format particularly appealed to advanced students due to its alignment with their competency development [34, 35]. For postgraduates, increased exam frequency heightened pressure and reduced project time, potentially explaining their lower acceptance [36, 37].

ChatGPT has become increasingly integrated into medical education as a tool for fostering critical thinking, with studies showing its effectiveness in providing a vast amount of information and simplifying complex concepts [38–41]. In this study, a blended teaching approach combining instructor guidance with ChatGPT was well-received by most students. However, clinical pharmacy education demands exceptional precision, as even minor errors could have serious consequences in future practice. While ChatGPT serves as a valuable resource, its responses are not always accurate, and students with limited expertise may struggle to verify their correctness. Therefore, advisor oversight remains crucial to evaluate and adjust ChatGPT's outputs, preventing potential misunderstandings. This interactive process also enhances students'information verification skills and reduces over-reliance on AI [42, 43]. For instance, requiring students to submit ChatGPT-generated answers for teacher verification encourages independent fact-checking, with incorrect responses affecting assessment scores. Additionally, reviewing ChatGPT interaction logs helps advisors identify knowledge gaps and tailor their teaching strategies. The biggest disadvantage of ChatGPT, as reported by students, is the lack of interaction, particularly because ChatGPT3.5 is currently used in China. This finding reflects that students believe that interaction with teachers is more valuable than their interactions with ChatGPT, affirming the key role of teachers in education. This sentiment was echoed by nearly three quarters of participants, who affirmed that ChatGPT cannot substitute for human instructors. This result underscores advisors'enduring role in guiding and verifying AI-assisted learning in clinical pharmacy education. This research reinforces the importance of a collaborative teacher-ChatGPT approach that leverages their complementary strengths while mitigating human limitations [44]. However, excessive AI dependence may reduce valuable student/teacher interactions and hinder independent thinking. Therefore, educational implementations must carefully delineate ChatGPT's role and use parameters. In this study, controlled ChatGPT usage with teacher oversight stimulated student engagement while maintaining educational quality. Moving forward, optimal implementation requires further exploration of usage occasions, time allocation, and supervision systems to maximize benefits while minimizing potential drawbacks in clinical pharmacy education. This balanced approach preserves the irreplaceable human elements of mentorship and verification while effectively incorporating AI's informational advantages.

There are several limitations to this study. First of all, post-training questionnaire responses may not capture students'immediate thoughts on teaching methods. Secondly, a separate control group was not established. Before the program reform started, students were asked about the new practices that would be put in place, and they were very interested. They did not want to join the traditional teaching group. Thirdly, the study focused on clinical pharmacy training for organ transplantation, which aligns with individualized medicine. This proposed teaching approach may not work out as well in other professional training contexts. Finally, the small number of respondents (only 81 responses) and the fact that some results were self-reported, with no evaluation by the advisors (e.g., critical thinking, communication skills), represent additional limitations of this study.

Conclusion

In this study, an AI-assisted multi-advisor system integrated with the BOPPPS teaching model was successfully implemented, demonstrating its effectiveness in modern clinical pharmacy education. By leveraging diverse instructor expertise, this approach not only delivers comprehensive theoretical knowledge but also cultivates multidimensional clinical reasoning in students. The findings confirm that structured methodologies like BOPPPS and OSCE significantly enhance student engagement, self-directed learning, and teacher-student interaction. Critically, ChatGPT, when used under guided supervision, serves as a powerful tool for improving learning efficiency while mitigating the risks of overreliance. By incorporating student feedback, the teaching framework was refined to address limitations and personalized syllabi were tailored to different majors and learning needs, thereby optimizing educational outcomes. This work provides a validated foundation for AI-enhanced pedagogical innovation.

Moving forward, these reforms will be expanded to advance more systematic and scalable improvements in pharmacy education.

Supplementary Information

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Supplementary Material 1.

Credit authorship statement

Qianqian Ye: Wrote the original draft, Visualization, Validation, Methodology, Investigation, Data curation. Shu Wang, Yufeng Liu, and Jinque Luo: Validation, Investigation, Data curation. Ziwei Deng: Validation and Visualization. Yueping Jiang and Shao Liu Validation, Resources, Project administration, Investigation. All authors reviewed the manuscript and agreed to the published version of the manuscript.

Authors' contributions

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Data availability

Data is provided within the manuscript or supplementary information files. Other datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate

The project was approved by the ethics committee of Xiangya Hospital, Central South University (No.202311223) and informed consent of all study participants. This study adhered to the principles outlined in the Declaration of Helsinki.

Consent for publication

Consent for publication is not applicable in this study, because there is not any individual person's data.

Competing interests

The authors declare no competing interests.

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