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Multi-objective teaching improves learning results: A randomized controlled trial

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Highlights

- Training with the multi-objective teaching model significantly improved in perioperative skills of residents.
- Multi-objective teaching model effectively facilitates the acquisition of comprehensive theoretical knowledge in anesthesiology.
- Multi-objective teaching model emphasizes the development of teamwork skills.

Abstract

Objective: The multi-objective teaching model is an educational strategy that aims to promote the holistic development of students through diverse teaching methods and activities. This study explores the application method of multi-objective teaching model in the standardized training of anesthesiology residents in China, aiming to enhance teaching outcomes and cultivate skilled anesthesiologists. **Methods:** A total of 60 anesthesiology residents undergoing standardized training at our center were included in this clinical observation. Participants (n=30/group) were randomly assigned to either the observation group (multi-objective teaching model) or the control group (conventional teaching model). All the participants received training on ultrasound-guided short-axis in-plane and short-axis out-of-plane axillary brachial plexus nerve block. In the control group, the teaching of the two kinds of punctures were carried out separately without comparison of the two or inclusion of additional puncture techniques. In the observation group, the teaching of the two kinds of puncture were integrated, and the experience was summarized and extended to the vascular and nerve puncture requiring similar technology. After the teaching of two different models, the difference of success rates in supraclavicular vein and internal jugular vein punctures were evaluated. **Results:** The observation group demonstrated a significantly shorter puncture and catheter placement time compared to the control group during supraclavicular vein and internal jugular vein puncture procedures (5.19±2.20 minutes vs. 8.35±2.40 minutes, P<0.01), with a higher success rate (76% vs. 64%, P=0.08). The number of mistaken arterial punctures was significantly reduced (4 cases vs. 8 cases, P=0.26). Additionally, both student and mentor evaluations of the multi-objective teaching model were significantly higher than those of the conventional model (student evaluation: 82±11 points vs. 71±9 points, P<0.01; mentor evaluation: 85±9 points vs. 76±7 points, P<0.01). **Conclusion:** The multi-objective teaching model significantly improves perioperative skills and teaching satisfaction among anesthesiology residents. It is an effective educational approach for enhancing anesthesiology training.

Keywords: Multi-objective teaching, anesthesia practice, residents training

Introduction

As continuous improvement of quality of life, there has been a corresponding increase in the demand for high-quality medical services. This requires clinicians to enhance their pro-

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fessional expertise and technical proficiency to minimize complications and reduce operational errors during perioperative period [1, 2]. The cultivation of competent young physicians, particularly in enhancing their clinical proficiency while ensuring patient safety, has emerged as a critical challenge in contemporary clinical education. While working as a visiting scholar in the Department of Anesthesiology of Dresden Technical University Hospital, Germany, the first author engaged in extensive clinical observations and identified significant differences in residency training approaches between China and Germany. These comparative insights, following systematic analysis and synthesis, have led to the proposition of implementing a multi-objective teaching model in the standardized training of anesthesiology residents in China. This proposed framework aims to provide valuable references for optimizing the cultivation of anesthesiology talents.

As a pivotal specialty in the surgical system, anesthesiology encompasses extensive clinical practices and diverse procedural contents. While various anesthesia centers in China have their specific protocols and guidelines, they generally adhere to the Chinese clinical practice guidelines. Significant conceptual differences exist between Chinese and German approaches to certain clinical operations [3, 4]. For example, in the ultrasound-guided axillary brachial plexus block, the standard practice involves using the short-axis in-plane approach, where the probe is positioned to visualize the neurovascular structures in cross-section, followed by needle insertion parallel to each nerve branch, which is easy to operate and provides direct visualization to prevent neurovascular injury. In contrast, German practitioners employ the short-axis out-of-plane approach, which is more difficult as it requires constant monitoring of the spatial relationship between the needle tip and neurovascular structures. Their explanation is that the axillary brachial plexus limb region is flat and broad, making it an optimal learning platform for out-of-plane perivascular nerve blocks. Their pedagogical rationale is that if trainees cannot master this technique in the most accessible anatomical location, they will be inadequately prepared for more complex procedures.

This educational philosophy extends to advanced epidural anesthesia techniques. German training programs deliberately assign skilled residents to practice thoracic puncture placement using the paramedian approach, despite its increased technical difficulty. This method proves particularly advantageous in challenging cases involving extensive calcification of the ligamentum flavum. Furthermore, despite the widespread availability of video laryngoscopes, German residency programs maintain rigorous daily training with conventional laryngoscopes to enhance residents' proficiency in managing difficult airways. These self-imposed technical challenges in clinical training embody the fundamental principles of the multi-objective teaching model, the core of which involves to incorporate higher-level training elements when residents demonstrate capacity beyond current instructional level [5].

The multi-objective teaching model represents a goal-oriented pedagogical approach that emphasizes the establishment of hierarchical teaching objectives throughout the training process, with corresponding training plans and instructional methodologies developed for each specific goal. This model aims to enhance the pertinence and efficacy of training, ensuring comprehensive acquisition of requisite knowledge and skills [6, 7]. In standardized residency training, we have consistently encountered several challenges: (1) a disparity between theoretical knowledge and practical skills among residents; (2) uneven proficiency across different clinical procedures, and (3) either insufficient challenge for high-performing residents or inadequate support for less proficient ones [8-10]. This dichotomy not only diminishes the motivation of exceptional residents but also poses potential clinical risks due to inaccurate competency assessment of less skilled residents.

To address these issues, we propose to implement multi-objective teaching model in China's standardized anesthesiology training program. In clinical practice, this approach involves: (1) establishing differentiated teaching objectives tailored to residents' competency levels, (2) implementing individualized instruction based on aptitude assessment, (3) recognizing their achievements upon completion of specific procedures, and (4) setting higher objectives for subsequent training phases.

Through this multi-objective teaching, we aim to provide individualized training that not only meets but potentially exceeds the final goals of standardized residency training. For this reason, we have initiated clinical teaching innovations that integrate continuous practice with systematic summarization. These efforts have led to the development of an enhanced training program, complemented by a refined evaluation system and safeguard mechanisms, all designed to ensure the effective implementation and desired outcomes of the multi-objective

Table 1. Comparison of original axillary brachial plexus nerve blocks ($\bar{x}$ ±SD)

	Control group (n=30)	Multi-objective teaching group (n=30)	t/χ^2value	P value
Operating time (min)	6.32±2.30	4.85±1.80	2.76	0.007
Success rate (%)	84	92	13.64	<0.001
Faulty penetration of artery (n)	2	0	2	0.157
Student evaluation (0-100 points)	80±6	92±8	6.58	<0.001
Mentor evaluation (0-100 points)	82±5	92±7	6.36	<0.001

teaching model.

Methods

Participant selection

A total of 60 anesthesiology residents undergoing standardized training at our center were included in this clinical observation. They were randomly assigned to either the observation group (multi-objective teaching model) or the control group (conventional teaching model), with 30 residents in each group. All the participants first received training on ultrasound-guided short-axis in-plane and short-axis out-of-plane axillary brachial plexus nerve block.

Control group

In the control group, training on ultrasound-guided short-axis in-plane and short-axis out-of-plane axillary brachial plexus nerve block was conducted according to the syllabus. Residents first received theoretical instruction on the procedures, including anatomy, ultrasound image recognition, operational steps, and complication prevention. After the theoretical teaching, residents performed simulated operations on mannequins or models to familiarize themselves with the procedures. Under the guidance of experienced instructors, residents observed actual procedures to deepen their understanding of the operational details before their clinical practice. Each resident completed each 15 cases of ultrasound-guided short-axis in-plane and short-axis out-of-plane axillary brachial plexus block to consolidate their learned knowledge and skills (**Table 1**). After each operation, instructors provided immediate feedback, recognizing the well-done procedures and pointing out what can be enhanced or improved, as well as organizing discussions to encourage peer learning.

Multi-objective teaching group

In the multi-objective teaching group, residents were introduced to the short-axis in-of-plane and short-axis out-of-plane axillary brachial plexus nerve block and underwent operation training. Our multi-objective teaching approach mandates that all clinical procedures be based on a comprehensive theoretical understanding, as only through theoretical guidance can we ensure procedural standardization and patient safety.

To achieve this, the multi-objective teaching model incorporates diverse instructional methodologies [11, 12].

• Interactive theoretical sessions: residents are encouraged to engage in questioning and discussions. These sessions systematically cover fundamental anesthesiology principles while incorporating contemporary advancements and evidence-based practices.

• Case-based learning: our curriculum employs authentic clinical cases to bridge theoretical knowledge with practical application. Each case is carefully selected to reflect a spectrum of clinical scenarios, from routine to complex situations. Residents engage in systematic case analysis, identifying key learning points and formulating management strategies.

• Structured group discussion: facilitated by experienced mentors, who initiate topic presentation and guide brainstorming, residents actively explore and discuss the topic, with key insights synthesized. This format promotes collaborative learning, critical thinking, and knowledge integration among residents.

• Mentorship and feedback: mentors play a crucial role in guiding discussions and providing real-time feedback. They ensure that the discussions remain focused, challenge residents to think critically, and provide insights based on their own experiences. Mentors also facilitates the translation of theoretical knowledge into clinical practice, helping residents to understand the practical implications of the theories they learn.

• Continuous assessment system: the program implements a robust evaluation framework that enables residents to monitor their progress and adapt learning strategies, allows mentors assess competency levels of residents at various training stages, ensuring that only those who demonstrate theoretical mastery and passing comprehensive assessments can proceed to clinical practice.

The multi-objective teaching model standardized training through a structured three-phase approach: simulation training, standardized clinical operations, and advanced clinical operations. Mentors outline the skills to be mastered at each stage and introduce the content for the next stage. Upon successfully completing the goals of current stage, residents progress to higher-level training for further development. The program mandates all residents to complete standardized clinical procedure assessments, with advanced clinical operation assessments available for high-performing residents demonstrating exceptional capacity.

Besides, the multi-objective teaching model underscores the importance of team collaboration among anesthesiology residents [13, 14]. Teamwork serves as a practical implementation mechanism for multi-objective teaching. With varying levels of experience within the team, residents can effectively complete tasks at their current stage through mutual discussion, sharing, and other collaborative activities. This helps residents avoid unnecessary pitfalls and risks in clinical practice, preparing for higher-level practice. Emphasizing collaboration among residents not only enhances residents' skills but also significantly improves teaching and work efficiency.

Additionally, the multi-objective teaching model also emphasizes the cultivation of professional quality among residents of anesthesiology, including responsibility, communication skills, and the ability to cope with pressure. The goal is not only to train residents with qualified professional skills but also to shape them into exceptional doctors with noble character, emotional intelligence, and a sense of professional honor, who can fulfill the Hippocratic Oath [15, 16]. The multi-objective teaching model enables residents to continuously improve themselves in practice by means of situation simulation and role-playing. By integrating these elements into the teaching model, this comprehensive approach aims to cultivate well-rounded doctors capable of navigating the complex landscape of medical practice with clinical excellence and ethical integrity. Therefore, this focus on professional ethics and character development constitutes a fundamental component of the multi-objective teaching model.

Both groups underwent training for two consecutive weeks, with each resident performing 15 actual operations. Two weeks later, residents from both groups were trained in ultrasound-guided short-axis plane supraclavicular vein and internal jugular vein catheterization, performing five clinical practices. The average puncture and catheter placement time, success rate, incidence of complications, and evaluations by both the residents and mentors were recorded. Our investigation focused on core anesthesiology procedures, including ultrasound-guided neurovascular puncture, epidural puncture and catheterization, comparing the efficacy of the multi-objective teaching model with conventional approaches, yielding significant comparative data.

Statistical analysis

Statistical analysis was performed using GraphPad Prism 7.0. The Kolmogorov-Smirnov test was used to check for normality. Normally distributed data were presented as mean ± standard deviation ($\bar{x}$ ±s). Inter-group comparisons were conducted using ANOVA, followed by Bonferroni post-hoc tests for pairwise comparisons. Categorical data were presented as frequencies (percentages) and analyzed using the χ^2 test. A P value of <0.05 was considered statistically significant.

Results

The results showed that compared with the control group, the multi-objective teaching group demonstrated significantly shorter puncture and catheter placement times, higher success rates, and fewer instances of arterial puncture errors during the subsequent supraclavicular and internal jugular vein puncture operations. Additionally, both trainees and instructors rated the multi-objective teaching model significantly higher than the conventional teaching model (**Tables 2-3**).

Discussion

Since 1993, the Ministry of Health issued the Notice on the Implementation of the Trial Measures for the Standardized Training of Clinical Residents, over 30 years have passed since the national realization of standardized and standardized resident training. In this vigorous development of medicine for more than 30 years, the standardized training system for resi-

Table 2. Comparison of supraclavicular vein puncture and placement ($\bar{x}$ ±SD)

	Control group (n= 30)	Multi-objective teaching group (n= 30)	t/χ^2 value	P value
Puncture and catheter placement time (min)	8.35±2.40	5.19±2.20	5.32	<0.001
Success rate (%)	64	76	5.14	0.023
Faulty penetration of artery (n)	16	8	4.44	0.035
Student evaluation (0-100 points)	71±9	82±11	4.24	<0.001
Mentor evaluation (0-100 points)	76±7	85±9	4.15	<0.001

Table 3. Comparison of internal jugular vein puncture and placement ($\bar{x}$ ±SD)

	Control group (n= 30)	Multi-objective teaching group (n= 30)	t/χ^2 value	P value
Puncture and catheter placement time (min)	6.59±2.10	4.73±1.90	3.60	<0.001
Success rate (%)	88	96	6.52	0.011
Faulty penetration of artery (n)	4	0	2	0.157
Student evaluation (0-100 points)	82±8	91±9	4.09	<0.001
Mentor evaluation (0-100 points)	84±7	93±9	4.33	<0.001

dent doctors has trained thousands of qualified clinical doctors. With the development of the times, some issues have gradually emerged in the teaching of resident standardized training, which need to be solved step by step in our practical work. For instance, the problem of increasing the success rate of operations and reducing complications, in the process of standardized training, requires residents to learn related techniques and content in a comprehensive and multi-objective manner within limited practical opportunities. Another issue is the singularity of the training syllabus and goals, which does not reflect "individualized" teaching. In the teaching process, the focus is mostly on meeting the minimum requirements for assessment, and for outstanding residents, there is rarely an expansion of learning content [7]. Additionally, there is a lack of proactive awareness among training mentors and undifferentiated teaching, which fails to set different goals based on the level of residents, leading to "the excellent students being under-challenged and the less capable ones struggling to keep up," thus dampening the motivation and enthusiasm for further learning [17-19]. All of these can be well solved by the multi-objective teaching model.

After comparing the differences in clinical anesthesia teaching practice between China and Germany, out center also made corresponding summaries and explorations. After a period of trial, we found that the multi-objective teaching model has the following advantages.

• Improving the pertinence of training: the multi-objective teaching model can make a personalized training plan according to the specific situation of each resident, to improve the pertinence and effect of training.

• Combination of multiple teaching methods: the multi-objective teaching model combines various teaching methods, allowing residents to better grasp knowledge and skills.

• Timely feedback and adjustment: the multi-objective teaching model focuses on timely feedback and adjustment, enabling residents to promptly understand their learning status and adjust their learning strategies.

• Cultivation of teamwork: the multi-objective teaching model places importance on the cultivation of teamwork, allowing residents to better integrate into teamwork.

• Improving professional ethics: the multi-objective teaching model stresses the development of professional ethics, enabling residents to continuously improve their professional ethics in practice.

The multi-objective teaching model, originally emerging in the foundational theoretical teaching of major universities, has achieved good results. Tian et al. put forward the hierarchical and multi-objective teaching model of Medical Statistics under the conditions of informatization, and adopted different teaching depths and methods among undergraduates, postgrad-

uates and foreign students, which fully aroused the enthusiasm of all kinds of students in learning and significantly improved their academic performance [20]. Sun et al. explored the multi-objective teaching model in the teaching of advanced mathematics, proposing various student-centered teaching methods to adapt to the construction and development of new engineering disciplines, and also achieved the expected teaching results [21]. In the practice of continuing medical education, some scholars have also proposed a stratified teaching method, which involves scientifically stratifying the trainees, developing individualized training programs, and conducting stratified teaching and assessment, thereby embodying the concept of individual differences and precise teaching [22, 23]. This method is part of the multi-objective teaching model we propose, which only advocates "teaching according to the aptitude of the learner" without integrating multi-objectives throughout the entire teaching process. The concept of multi-objective teaching is to provide individualized teaching to residents at different levels at different stages, but during the teaching process, it also sets higher-level requirements so that after completing the current teaching goals, progress can be made toward higher levels. Moreover, the multi-objective concept is not only for residents, but we hope to fully reflect the multi-objective philosophy in the design of the syllabus, the initiative of the mentors, and the aspects of humanities and professional ethics.

One of the limitations of our study is the relatively small sample size of 60 anesthesiology residents. This restricts the generalizability of our findings and may affect the statistical power of our comparisons. The small sample size also limits our ability to draw definitive conclusions about the long-term effects of the multi-objective teaching model on residents' professional development. To address these limitations, future research should aim to include larger and more diverse cohorts of residents from multiple centers. This would enhance the external validity of the findings and allow for more robust statistical analysis. Additionally, longitudinal studies could be conducted to assess the sustained impact of the multi-objective teaching model on residents' skills and professional growth over time.

While this study aimed to explore the application of the multi-objective teaching model in China, it is essential to acknowledge the potential challenges and limitations that may arise when adopting this model. One significant challenge is the differences in healthcare systems and educational infrastructures between Germany and China. The German healthcare system's emphasis on standardized procedures and advanced technology may not be as readily available in all Chinese medical institutions, which could hinder the implementation of certain teaching methods. Additionally, resource constraints, such as the availability of qualified instructors and state-of-the-art equipment, could limit the effectiveness of the multi-objective teaching model in some settings. The disparities in regional development within China mean that not all medical facilities may have the capacity to support this model, particularly in rural or less developed areas.

Conclusions

The multi-objective teaching model has obvious advantages in the training of anesthesiology residents, which can comprehensively improve the theoretical knowledge, clinical skills, teamwork ability and professional quality of residents. Through continuous optimization and improvement of the multi-objective teaching model, the quality of resident training can be enhanced, contributing more to the development of the medical profession.

Author contributions: Kai Wang contributed to the conception of the study. Kai Wang and Zhe Zhang performed the experiment. Mingling Wang and Shiming Feng contributed significantly to analysis and manuscript preparation. Kai Wang performed the data analyses and wrote the manuscript. Huanjia Xue and Xiang Huan helped perform the analysis with constructive discussions. Liwei Wang supervised the study and contributed to the analysis through constructive discussions.

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