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Application of Neurointerventional Vascular Model Combined with Mind Map in Cerebral Angiography Teaching

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Research Article

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Abstract

Objective

To explore the application value of neurointerventional vascular model combined with mind map in cerebral angiography teaching, and to provide evidence for optimizing neurointerventional teaching models.

Methods

Eighty-four clinical medical students without neurointerventional clinical experience were randomly divided into three groups: control group, mind map group (MM group), and vascular model + mind map group (VM + MM group), with 28 students in each group. The control group adopted the traditional teaching method combining theoretical lectures and video demonstrations; the MM group added mind map-assisted teaching on the basis of traditional teaching; the VM + MM group adopted the teaching model combining vascular model operation and mind map-based knowledge system construction. After the teaching, the teaching effect was evaluated through theoretical assessment, operational skill assessment, clinical thinking scoring, and teaching satisfaction questionnaire, and statistical analysis was performed using SPSS 26.0.

Results

The theoretical assessment score (89.64 ± 4.28), operational skill score (90.17 ± 3.85), clinical thinking score (88.93 ± 4.12), and teaching satisfaction rate (96.43%) of the VM + MM group were significantly higher than those of the MM group [(82.31 ± 5.16), (81.54 ± 4.72), (80.26 ± 4.58), 82.14%] and the control group [(75.42 ± 6.33), (73.29 ± 5.26), (72.85 ± 5.03), 67.86%], with statistically significant differences ($P < 0.05$). All indicators of the MM group were superior to those of the control group, and the differences were also statistically significant ($P < 0.05$).

Conclusion

In this single-center controlled trial, the teaching model combining neurointerventional vascular model and mind map significantly improved the short-term learning outcomes (theoretical mastery, simulated operational skills, and clinical thinking) of cerebral angiography teaching for novice clinical medical students without neurointerventional experience, and showed more advantages than single teaching methods. This model has potential as an optimized teaching approach for neurointerventional novice training, but its generalizability requires further verification by multi-center and long-term follow-up studies.

Introduction

Cerebral angiography (Digital Subtraction Angiography, DSA), as the "gold standard" for neurointerventional diagnosis and treatment, is one of the core skills that neurosurgeons and

interventional physicians must master. This procedure requires high precision, involves complex vascular anatomical structures, and has strict requirements for intraoperative risk control. The traditional teaching model dominated by "theoretical lectures + video demonstrations" has problems such as fragmented knowledge, lack of practical experience, and insufficient cultivation of clinical thinking, making it difficult for students to quickly construct a three-dimensional cognitive framework of "anatomical structure-operational process-risk prediction" [1].

Neurointerventional vascular models can simulate the anatomical structure and operational feel of intracranial blood vessels, making up for the lack of clinical practical operation opportunities and helping students build spatial positioning ability; mind maps can integrate scattered knowledge through a visualized hierarchical structure, strengthen logical connections, and improve the efficiency of knowledge internalization [2–4]. In recent years, the application effect of single auxiliary teaching tools in medical education has been confirmed, but the effect of their combined application in cerebral angiography teaching is still lacking systematic research [5]. This study explored the application value of the combined teaching model of vascular model and mind map through a three-group controlled trial, so as to provide clinical reference for the reform of neurointerventional teaching.

Materials and Methods

Study Subjects

Eighty-four clinical medical students who received neurosurgical training in our hospital from January 2024 to December 2024 were selected as the research subjects, all of whom had no neurointerventional clinical or operational experience. The students were divided into control group, mind map group (MM group), and vascular model + mind map group (VM + MM group) using a random number table method, with 28 students in each group.

Teaching Materials

The vascular model was a neurointerventional vascular model produced by Ningbo Chuangdao 3D Medical Technology Co., Ltd., which can accurately simulate key anatomical structures such as the radial artery, femoral artery, aorta, and carotid artery, and can be used for training operations such as cerebral infarction thrombectomy, aneurysm embolization, and cerebral angiography. The mind map tool adopted XMind 2023. The teaching team constructed a standardized mind map template covering core modules such as cerebral vascular anatomy, DSA equipment operation, angiography process, and complication management based on the *Guidelines for Neurointerventional Diagnosis and Treatment* and typical clinical cases, so as to build a systematic knowledge framework for students.

Teaching Methods

The teaching content of the three groups centered on the core knowledge points of cerebral angiography, with a total teaching duration of 40 class hours (20 class hours for theory + 20 class hours for practice), taught by the same group of senior neurointerventional physicians.

Control Group

Adopting the traditional teaching model: theoretical courses explained cerebral vascular anatomy, DSA principles, operational steps, and complications through PPT; practical courses played standard operation videos, and students were commented on by teachers after observation, with no practical training or mind map assistance arranged.

Mind Map Group (MM Group)

Added mind map teaching on the basis of the control group: mind map templates and preview tasks were issued three days before class to guide students to improve the knowledge framework in combination with textbooks; during class, mind maps were used as clues to connect theoretical knowledge points and case analysis, strengthening the correlation between knowledge; after class, students were required to optimize mind maps in combination with classroom content to form personalized notes, which were reviewed and feedback was given by teachers one by one.

Vascular Model + Mind Map Group (VM + MM Group)

Adopting the combined teaching model: the theoretical part was the same as that of the MM group, and the practical courses carried out practical operation training combined with vascular models. Students first sorted out the operational process according to the mind map, then performed practical operation training such as guidewire and catheter placement and angiography position adjustment on the vascular model. Teachers disassembled and explained the operational difficulties in combination with mind maps; after class, the practical operation process was reviewed through mind maps, and operational errors and improvement points were marked, forming a closed-loop teaching of "theory - mind map - practice".

Research Design Flow Chart

To clearly show the complete process of student grouping, teaching implementation, and assessment, a flow chart is drawn as follows(Fig. 1).

Evaluation Indicators

Theoretical Assessment

A closed-book examination was adopted, including single-choice questions, multiple-choice questions, and case analysis questions, with a full score of 100. The examination focused on assessing knowledge points such as cerebral vascular anatomy, DSA equipment principles, angiography indications, and complication management.

Clinical Thinking Scoring

Three complex cerebral vascular cases (cerebral aneurysm, cerebral vascular stenosis, arteriovenous malformation) were provided, requiring students to formulate angiography plans and analyze potential risks. Scoring was conducted from four dimensions: case assessment, plan rationality, risk prediction, and emergency treatment, with a full score of 100.

Operational Skill Assessment

Referring to the internationally accepted cerebral angiography skill scoring system [6], quantitative scoring was carried out from 10 dimensions including equipment preparation, sterile operation, guidewire and catheter manipulation, angiography position selection, and radiation protection, with a full score of 100. Two experienced neurointerventional physicians conducted independent assessments using a blind method, and the average value was taken as the final score. At the same time, the time taken for students to complete the full-process operational assessment was recorded to reflect operational proficiency.

Teaching Satisfaction

A self-designed questionnaire was developed specifically for this study to evaluate students' teaching satisfaction, adopting a Likert 5-point scale (https://www.scribbr.com/methodology/likert-scale/). The questionnaire was constructed based on the core objectives of cerebral angiography teaching and expert consensus of neurointerventional educators, evaluating from four dimensions: knowledge understanding, skill improvement, interest stimulation, and thinking cultivation, with a total of 16 items (Cronbach's $\alpha = 0.89$, indicating good internal consistency of the questionnaire). A total score of ≥ 4 was considered satisfactory, and the satisfaction rate was calculated. An English version of this self-designed questionnaire is provided as a supplementary file (see Supplementary File 1) of this manuscript.

Statistical Methods

SPSS 26.0 statistical software was used for data analysis. Measurement data were expressed as ($x \pm s$), and inter-group comparison was performed using one-way analysis of variance; count data were expressed as rate (%), and inter-group comparison was performed using χ^2 test. $P < 0.05$ was considered statistically significant.

Results

Comparison of Baseline Data of Students

A total of 84 students were included in this study, and they were divided into three groups with 28 students in each group using a random number table method. The comparison of baseline indicators such as gender composition, average age, educational background distribution, and clinical work duration among the three groups of students showed no statistically significant differences (P > 0.05), which ensured the objectivity and reliability of subsequent teaching interventions and result comparisons. The specific baseline data are shown in Table 1.

Table 1
Comparison of baseline data among the three groups of students

Group	Number of cases (n)	Gender (Male/Female, n)	Age (x ± s, years)	Educational background (n, %)		Working time (x ± s, years)
				Bachelor's degree	Master's degree	
Control group	28	25/3	26.3 ± 2.1	18 (64.3%)	10 (35.7%)	1.8 ± 0.9
MM group	28	26/2	25.9 ± 2.3	17 (60.7%)	11 (39.3%)	1.7 ± 1.0
VM + MM group	28	24/4	26.5 ± 2.0	19 (67.9%)	9 (32.1%)	1.9 ± 0.8

Note: There were no statistically significant differences in baseline indicators among the three groups (all P > 0.05), indicating comparability. There were no doctoral students among the educational backgrounds, only bachelor's and master's degrees; working time refers to the total duration of clinical work, and none of them had neurointerventional-related work experience.

Comparison of Theoretical Assessment and Clinical Thinking Assessment Scores of Students

The VM + MM group was significantly higher than the MM group and the control group in the two core scores of theoretical assessment and clinical thinking. All indicators of the MM group were also superior to those of the control group, and the inter-group differences were statistically significant (P < 0.05). This suggests that both the combined teaching model and single mind map-assisted teaching are superior to traditional teaching, and the combined model has the best effect. The specific results are shown in Table 2.

Table 2
Comparison of theoretical assessment and clinical thinking scores among the three groups (x ± s, points)

Group	Number of trainees(n)	Theoretical assessment	Clinical thinking
Control group	28	75.42 ± 6.33	72.85 ± 5.03
MM group	28	82.31 ± 5.16*	80.26 ± 4.58*
VM + MM group	28	89.64 ± 4.28*#	88.93 ± 4.12*#
Note: Compared with the control group, *P < 0.05; compared with the MM group, #P < 0.05.			

Comparison of Operational Skill Assessment of Students

The combined analysis of operational skill assessment duration and scores showed that the VM + MM group not only had the highest operational score but also had a significantly shorter assessment duration than the MM group and the control group; the MM group was superior to the control group in both assessment duration and score, and the inter-group differences were statistically significant (P < 0.05), indicating that the combined teaching model can improve both the operational proficiency and accuracy of students. The specific results are shown in Table 3.

Table 3
Comparison of operational skill assessment and teaching satisfaction among the three groups

Group	Number of trainees(n)	Assessment duration (x ± s, min)	Operational skill score (x ± s, points)	Satisfaction rate(%)
Control group	28	38.6 ± 4.5	73.29 ± 5.26	67.86(19/9)
MM group	28	31.2 ± 3.8	81.54 ± 4.72*	82.14(23/5)*
VM + MM group	28	25.8 ± 3.2*#	90.17 ± 3.85*#	96.43(27/1)*#
Note: Compared with the control group, *P < 0.05; compared with the MM group, #P < 0.05; the shorter the assessment duration, the higher the operational proficiency.				

Comparison of Teaching Satisfaction of Students

A Likert 5-point scale was used to conduct a self-reported teaching satisfaction survey, evaluating from four dimensions: knowledge understanding, skill improvement, interest stimulation, and thinking cultivation. A total score of ≥ 4 was set as the satisfaction standard. The results showed that the teaching satisfaction rate of the VM + MM group was significantly higher than that of the MM group and the control group, and the satisfaction rate of the MM group was higher than that of the control group, with statistically significant differences among groups (P < 0.05), which was consistent with the trend of

assessment results, confirming the advantage of the combined teaching model in teaching experience. The specific results are shown in Table 3.

Discussion

Advantage Analysis of the Combined Teaching Model

Strengthen Knowledge System Construction and Improve Theoretical Mastery

The anatomical structure of cerebral blood vessels is extremely complex, and knowledge points are scattered. Under the traditional indoctrinative teaching model, students are prone to fragmented knowledge memory and vague logical connections. Mind maps adopt a hierarchical and visualized presentation method, which can help students quickly build a knowledge network of "core knowledge points - branch content - related key points", greatly improving the efficiency of knowledge internalization and retention [7, 8]. In this study, the theoretical score of the MM group was superior to that of the control group, which fully confirms the core role of mind maps in knowledge integration [3]. The VM + MM group carried out practical operations through vascular models, transforming abstract anatomical knowledge into specific operational experience, further strengthening the in-depth connection between theory and practice, and promoting students' understanding of knowledge points from the "memory" level to the "application" level. Therefore, this group achieved the best theoretical results [4]. Existing studies have shown that the combination of visualization tools and practical training can increase the retention rate of medical knowledge by more than 30% [9], which is consistent with the results of this study.

Make Up for Practical Shortcomings and Improve Operational Skills

Neurointerventional operations have extremely high requirements for precision, and there are limited opportunities for clinical practical operations, as well as risks such as vascular injury and contrast medium extravasation. Vascular models provide a safe and controllable simulated training platform for students [2].

Through repeated practical operations on the model, students can proficiently master guidewire and catheter manipulation skills, accurately judge resistance, and master the skills of catheter positioning in complex anatomical sites such as the carotid siphon, thereby establishing muscle memory and spatial positioning ability, which can significantly reduce the risk of adverse events in the early stage of clinical practical operations [10].

The core of the operational skill advantage of this group lies in the synergistic effect of "mind map + vascular model": mind maps sort out the operational process and clarify key nodes, thereby avoiding

blind practical operations [7]; practical operations on the model can verify and strengthen the key points in mind maps, forming a closed loop of "thinking - action" linkage. Especially in details such as the accuracy of angiography positions and the standardization of radiation protection, the improvement effect is more significant.

Cultivate Clinical Thinking and Improve Diagnosis and Treatment Capabilities

The core goal of cerebral angiography teaching is to cultivate students' comprehensive ability of "operation based on anatomy and decision-making based on cases". In the combined teaching model, mind maps can help students systematically integrate case information, operational processes, and risk factors to build a standardized decision-making framework; vascular models provide a practical operation scenario for simulated decision-making, allowing students to learn to coordinate "anatomical characteristics - operational plans - risk prediction" during training and gradually form clinical thinking [11].

In this study, the VM + MM group had the highest clinical thinking score, indicating that this model can effectively break the barrier of "disconnection between theory and practice" in traditional teaching, promote students' transformation from "passive execution" to "active decision-making", and improve comprehensive diagnosis and treatment thinking. Integrated simulation training can strengthen clinical reasoning ability [12].

Stimulate Learning Initiative and Improve Teaching Experience

In traditional teaching, students are in a passive state of accepting knowledge, and their learning enthusiasm is easily inhibited [1]. The combined teaching model stimulates students' initiative through dual interactive design. Among them, mind maps allow students to optimize the knowledge framework according to their own understanding, form personalized notes, and enhance the sense of ownership of knowledge [3]; practical operations on vascular models provide an immersive experience, enabling students to discover and solve problems during hands-on operations and improve the sense of achievement in learning [2, 5]. The satisfaction survey showed that the VM + MM group had the highest recognition among students. Most students reported that this model can reduce learning difficulty and stimulate exploration interest, which is closely related to the fun of mind maps and the immersion of model practical operations [13], and is also consistent with the research result proposed by Strebl et al. that "simulation + visualization tools can improve teaching experience" [14].

Limitations and Optimization Strategies of the Combined Teaching Model

The core limitation of the combined teaching model is the high teaching input required, which hinders its large-scale popularization in medical education. Neurointerventional vascular models, especially high-

fidelity intelligent versions, are costly to procure; in addition, consumables including simulated vascular walls and training guidewires and catheters are either disposable or have a limited service life, resulting in considerable annual consumable costs. As noted in a study by Nawka et al. [15], although modular vascular simulators can reduce partial expenses, they remain unaffordable for primary medical teaching institutions with limited educational budgets.

The implementation of the combined teaching model also requires additional time investment, which is inconsistent with the fixed duration of standardized clinical training [16]. Pre-class preview of mind map templates, in-class sorting of knowledge frameworks, and post-class optimization of mind maps, as well as the review and summary of operational experience after vascular model practice, all demand extra learning time from students. Although this study unified the total teaching duration at 40 class hours for all groups, practical implementation found that students with weaker foundational medical knowledge struggle to complete the closed-loop learning of "mind map optimization - precise practical operation - problem review" within the specified time, which is likely to cause learning pressure and even reduce the overall training effect.

Moreover, there are inherent gaps between the vascular model and actual clinical operating scenarios, leading to a limited skill transfer effect of simulated training [17]. Most current vascular models are designed based on standardized cerebral vascular anatomical structures, which fail to cover the diverse anatomical variations encountered in clinical practice. Meanwhile, these models cannot simulate the impact of real clinical factors such as patient blood pressure fluctuations and individual differences in vascular elasticity on surgical resistance and operational decisions. This thus compromises students' adaptive capacity when they face anatomical variations of cerebral blood vessels in actual clinical work [18].

In view of the above limitations, three targeted optimization strategies are proposed in combination with existing research results. First, in terms of cost control, academic and industrial cooperation should be strengthened to develop low-cost, high-fidelity vascular models, and degradable simulation materials should be adopted to cut down consumable costs. A modular model library containing common cerebral vascular anatomical variations should also be established to balance the economic efficiency and clinical authenticity of the training model. Second, in terms of teaching adaptation, a stratified teaching combined with modular training model should be implemented: the complexity of mind map frameworks is split according to students' foundational knowledge level, the time allocation for theoretical learning and practical operation is optimized, and additional basic operation training hours on vascular models are provided for students with weak foundations [19]. Third, in terms of improving skill transfer efficiency, VR-vascular model fusion technology should be introduced to simulate hemodynamic changes and sudden intraoperative complications through VR technology; simulated training should also be combined with the review of real clinical cases to narrow the gap between simulated training and actual clinical cerebral angiography operations [14, 18].

Conclusion

This study confirms that the teaching model combining the neurointerventional vascular model and mind map can significantly improve students' theoretical mastery, operational skills and clinical thinking ability in cerebral angiography teaching through the synergistic effect of "knowledge integration - practical strengthening - thinking cultivation". This combined model outperforms the single mind map-assisted teaching and traditional teaching models in both objective teaching effect evaluation and subjective student teaching satisfaction, and thus serves as a promising optimized approach for neurointerventional teaching for novice learners without clinical interventional experience.

Nevertheless, this model still has practical limitations such as high teaching and consumable costs, which need to be addressed through technological innovation and multi-institutional resource sharing. Future research could further expand the sample size, and conduct multi-center and long-term follow-up studies to evaluate the long-term impact of this combined model on students' independent clinical operation ability and knowledge retention efficiency. In doing so, more sufficient and scientific evidence can be provided for the standardization and optimization of neurointerventional teaching curricula and training models in medical education.

Declarations

Ethics approval and consent to participate

This study was submitted to and formally approved by the Institutional Review Board of Sir Run Run Shaw Hospital, College of Medical Sciences, Zhejiang University. No specific approval reference number was assigned in accordance with the committee's review regulations. The study was designed and conducted in strict adherence to the ethical principles of the World Medical Association (WMA) Declaration of Helsinki (Revised in 2024) for research involving human participants. All participants were provided with a detailed written explanation of the study's purpose, teaching intervention protocols, assessment methods, and the voluntary nature of participation. All participants gave their informed written consent prior to the commencement of the study, and participants had the right to withdraw from the study at any time without any adverse impact on their normal clinical training.

Consent for publication

Not applicable

Competing interests

None.

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None.

Author Contribution

Dajiang Xie designed the study, collected data, performed statistical analysis, drafted the manuscript and revised the manuscript.

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Not applicable

Data Availability

The data presented in this article is available upon request from the corresponding author.

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Figures

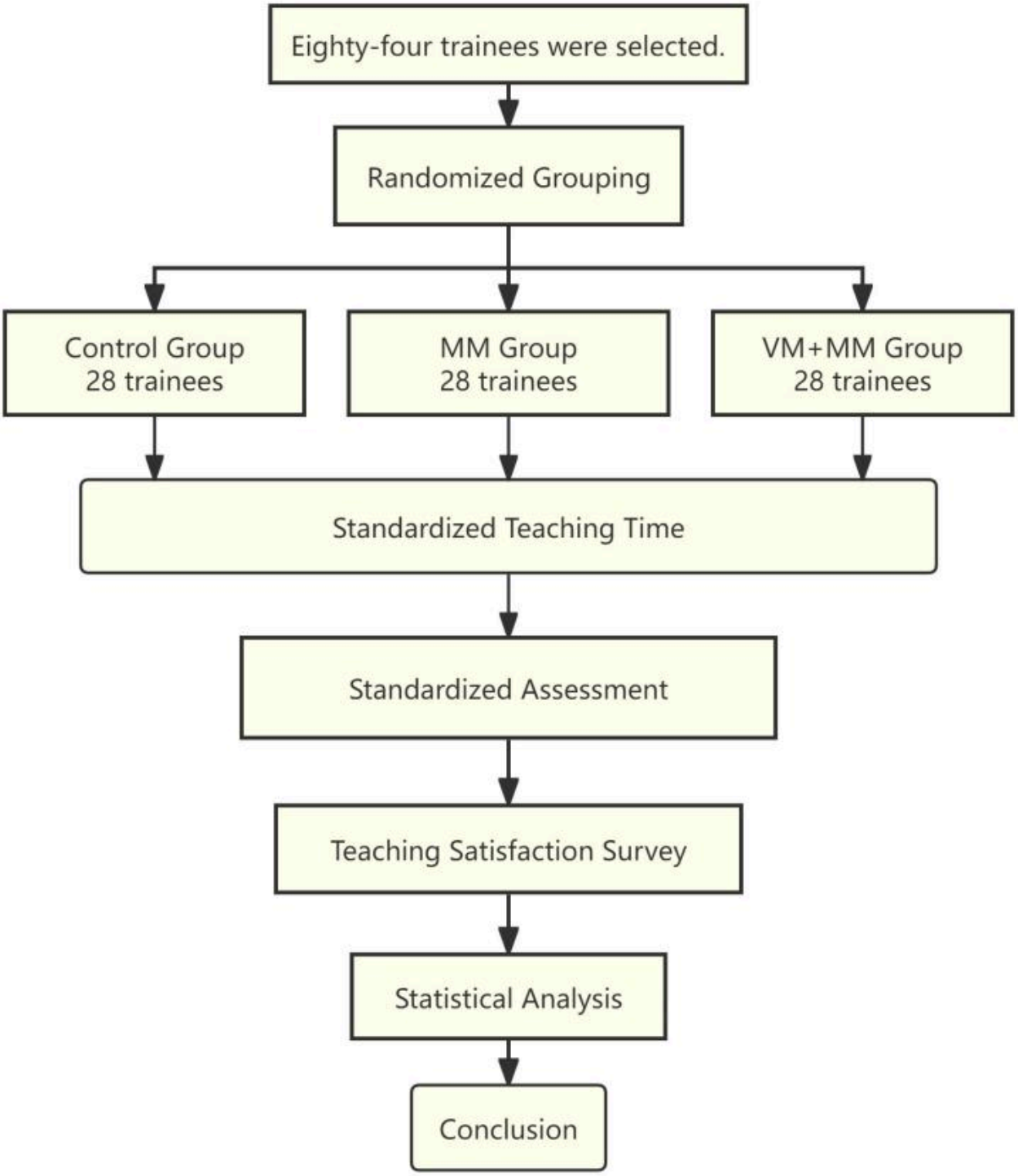


Figure 1

Flow chart of complete process.

Supplementary Files

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