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Application of Cutting-edge Medical Case-based Teaching Method in Graduate Neuroanatomy Education

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Abstract: *Objective:* To evaluate the effectiveness of cutting-edge medical case-based teaching method in graduate neuroanatomy education. *Methods:* Graduate students enrolled in a neuroanatomy course were divided into two groups: a conventional Case-Based Learning (CBL) group and a CBL group with integration of medical frontiers. In the conventional CBL group, clinical cases and guiding questions were introduced prior to lectures. In the experimental group, recent developments in neuroscience were integrated through interactive methods, including scenario-based simulations, group discussions, and instructor-led debriefings. Teaching outcomes were evaluated through theoretical examinations, laboratory skills assessments, student interviews, and structured questionnaires. *Results:* The CBL group with medical frontier integration demonstrated significantly improved performance in fundamental theory, diagnostic analysis, and scientific writing compared to the conventional CBL group. Students reported greater satisfaction and engagement with the course. Moreover, they showed marked improvements in applying theory to clinical analysis and hands-on tasks. Enhancements were also observed in clinical reasoning, research literacy, critical thinking, teamwork, and problem-solving abilities. *Conclusion:* Cutting-edge Medical case-based teaching significantly improves the effectiveness and quality of graduate neuroanatomy education. This approach provides valuable direction for medical education reform and holds strong potential for broader application across diverse medical disciplines.

Keywords: Neuroanatomy; Case-based teaching; Medical frontiers; Scientific thinking; Graduate education

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1. Introduction

In graduate medical education, neuroanatomy is a core foundational course that serves as a critical bridge between theory and practice, as well as between basic science and clinical application [1]. It not only elucidates the intricate structural organization of the human nervous system but also lays a solid theoretical foundation for understanding neural functions, the pathogenesis of neurological disorders, and potential therapeutic strategies [2]. However, traditional approaches to neuroanatomy instruction, predominantly didactic lectures and cadaverbased dissection, tend to emphasize rote knowledge and technical skills while lacking contextualized clinical relevance and interactive engagement. As a result, these methods often fall short in stimulating students' interest and intrinsic motivation [3]. With the rapid advancement of medical technologies in recent years, neuroscience has witnessed a surge of innovative research and technological breakthroughs. These developments have significantly enriched the knowledge base of neuroanatomy and opened new avenues for pedagogical innovation. A pressing challenge in current medical education reform is how to effectively integrate these cutting-edge findings into teaching, enabling students to master fundamental concepts while also engaging with the latest scientific advancements and technological tools. In response to this challenge, instructional models such as Problem-Based Learning (PBL) and Case-Based Learning (CBL) have been increasingly adopted in neuroanatomy education [4,5]. These methods focus on fostering students' ability to apply theoretical knowledge in real clinical contexts and to think critically when solving complex problems. Among these, case-based analysis stands out as a particularly effective strategy, as it connects abstract anatomical concepts with tangible clinical cases, thereby enhancing both the relevance and practicality of the learning experience [6,7]. This study introduces a novel teaching approach that combines case-based learning with the integration of frontier medical research and applies it in the context of postgraduate neuroanatomy instruction. Carefully curated clinical cases are used to guide students in exploring neuroanatomical structures through real-world problem-solving, while the incorporation of up-to-date research allows students to engage with the forefront of scientific discovery. This dual approach not only enriches their learning experience but also inspires a spirit of inquiry and innovation. Through educational practice and reflective evaluation, this study aims to examine the advantages and challenges of this integrated teaching model in improving instructional effectiveness and enhancing students' comprehensive competencies. The findings are expected to offer valuable insights for future medical curriculum reform.

2. Materials and methods

2.1. General information

A total of 72 first-year clinical medicine master's students enrolled at our university in 2023 were selected and randomly assigned to two groups: the CBL group (n = 32) and the CBL with Cutting-edge Integration group (n = 40). In the CBL group, only clinically relevant teaching cases were introduced prior to theoretical instruction, accompanied by guiding questions. In contrast, the CBL with Cutting-edge Integration group incorporated the latest research findings from the field of neuroscience into the teaching process. This was achieved through the creation of simulated classroom scenarios, group discussions among students, and instructor-guided debriefings. The effectiveness of neuroanatomy instruction was compared between the two groups using case-based analysis as the core instructional strategy.

2.2. Methods

Representative clinical teaching cases covering key knowledge points were carefully selected and jointly prepared by anatomy instructors, clinicians, and neuroscience researchers. Based on the course objectives and syllabus requirements, content was curated to include foundational knowledge in neuroscience, recent scientific advances, and relevant clinical applications, ensuring both educational value and the ability to stimulate students' interest and curiosity. Anatomy instructors were responsible for outlining the fundamental framework of neuroscience and designing teaching strategies and assessment methods aligned with students' cognitive levels. Multimedia tools, such as animations and videos, were employed to visualize abstract concepts and enhance comprehension.

Clinicians contributed by presenting real clinical cases, highlighting key aspects of diagnosis and treatment processes. Neuroscience researchers introduced the latest scientific findings and research methodologies to broaden students' academic horizons. The actual instruction was delivered by anatomy instructors. The detailed course structure is presented in **Table 1**.

Table 1. Neuroanatomy topics, clinical case analyses, and relevant medical frontiers.

Teaching Content	Clinical Case	Case Analysis	Relevant Medical Frontiers
General Overview of the Nervous System	Guillain–Barré Syndrome	Demyelinating lesions of the peripheral nerves	(1) Mesenchymal stem cell therapy to promote nerve regeneration and reduce inflammation; (2) Novel neuroprotective agents such as N-acetylcysteine and statins may protect neurons by reducing oxidative stress and inflammation.
Cranial Nerves	Facial Nerve Paralysis	Damage or lesion of the facial nerve	(1) Gene therapy to enhance facial nerve regeneration and functional recovery; (2) RNA interference (RNAi) to suppress pro-inflammatory mediators and reduce nerve inflammation; (3) Nanotechnology-based drug delivery systems for targeted therapy; (4) Bioactive scaffolds combining growth factors and cells to promote nerve regeneration.
Spinal Nerves	Lumbar Disc Herniation	Disc degeneration and spinal nerve root compression	(1) Percutaneous laser disc decompression; (2) Stem cell therapy to promote repair and regeneration of the nucleus pulposus and annulus fibrosus; (3) Injection of growth factors (e.g., TGF-β) into intervertebral discs to stimulate cell proliferation and matrix synthesis.
Spinal Cord	High-level Paraplegia	Cervical spinal cord injury	(1) Electrical and magnetic stimulation of the spinal cord to promote functional recovery; (2) Novel anti-inflammatory agents such as Tocilizumab to alleviate post-injury inflammation.
Brainstem	Parkinson's Syndrome	Midbrain lesion	(1) Focused ultrasound for precise targeting and ablation of pathological tissue to relieve motor symptoms; (2) Stem cell therapy to replace damaged dopaminergic neurons or support neuroregeneration; (3) CRISPR/Cas9 gene editing to repair mutations such as *LRRK2* and *PINK1* associated with Parkinson's disease.
Telencephalon	Alzheimer's Disease	Progressive hippocampal neuron loss and corpus callosum fiber degeneration	(1) *APOE ε4* allele as a genetic risk factor—mechanistic studies ongoing; (2) Monoclonal antibodies (e.g., Aducanumab) for amyloid-β clearance; (3) Development of monoclonal antibodies and small molecule inhibitors targeting tau protein phosphorylation and aggregation.
Cerebellum & Diencephalon	Cerebellar Ataxia	Lesions in the cerebellum or its pathways	(1) Protein aggregation (e.g., SCAs) and mitochondrial dysfunction in cerebellar degeneration; (2) Clinical trials of drugs such as Vigabatrin, Gabapentin, and Riluzole; (3) Role of neurotrophic factors (BDNF, NGF) and antioxidants in protecting cerebellar neurons.
Neural Pathways	Thalamic Pain Syndrome	Tumor compression or infarction in the middle cerebral artery territory	(1) Stem cell transplantation; (2) CRISPR/Cas9 gene editing for correcting mutations and promoting nerve repair; (3) Role of neurotrophic factors like GDNF in neuronal protection and regeneration; (4) Multimodal rehabilitation training and assistive technology development.
Meninges of Brain & Spinal Cord	Meningitis	Meningeal pathology	(1) Standardized diagnosis and treatment per the 2023 Chinese National Guidelines for Epidemic Meningitis; (2) Genetic sequencing for pathogen-specific diagnosis; (3) Immunomodulatory and combination immunotherapies to improve neurological outcomes; (4) Development of multivalent vaccines.
Cerebral and Spinal Vessels	Acute Ischemic Stroke	Vascular lesions in the middle cerebral or vertebral arteries	(1) Exploration of microRNAs (e.g., miR-124, miR-21, miR-210) and protein biomarkers for early diagnosis and prognosis; (2) Stem cell therapies (e.g., MSCs, NSCs) to promote neural regeneration; (3) Immunomodulators such as IL-1 receptor antagonists and TNF-α inhibitors to reduce inflammation.
CSF Circulation & Brain Barriers	Hydrocephalus	Obstruction of cerebrospinal fluid circulation	(1) Use of biomarkers such as amyloid-β, tau protein, S100B, and related microRNAs for diagnosis and prognosis; (2) Development of novel drugs and therapeutic strategies to prevent and manage hydrocephalus.

To illustrate the implementation of the teaching process, the case of facial nerve palsy was used as an example. The instructor first introduced a clinical case: a 47-year-old male patient presented with sudden-onset left-sided facial weakness, drooping of the mouth corner, and inability to fully close the left eye. The symptoms were accompanied by mild pain near the left ear upon touch, inability to raise the left eyebrow, move the left side of the lips, or puff the cheeks. Drinking led to water leakage from the left corner of the mouth. The patient had no previous medical history, and symptoms appeared suddenly within 24 hours. Physical examination showed no visible trauma on the left face, but notable findings included drooping of the mouth corner, incomplete eyelid closure, and reduced function of the left facial nerve, manifesting as weakness in the frontalis, orbicularis oculi, and orbicularis oris muscles. Taste perception was diminished in the anterior two-thirds of the tongue on the left side. The preliminary diagnosis was facial nerve palsy. Based on the case, the instructor posed the following questions for student discussion: (1) What is the anatomical basis of facial nerve palsy? At which anatomical sites is the facial nerve most vulnerable to injury or compression? (2) What other related structures may be involved in facial nerve palsy? How can the anatomical features of the facial nerve explain the observed functional impairments? (3) For left-sided facial nerve palsy, which anatomical sites should be prioritized in treatment? How do prognosis and treatment strategies differ based on the site of nerve injury? (4) Is this type of facial palsy reversible? What anatomical factors may influence nerve regeneration and functional recovery?

Students were divided into four groups, each assigned a group leader responsible for organizing and coordinating discussions to ensure orderly conduct and appropriate time management. Each group also included: a recorder to document key points, questions, and solutions; two researchers to search relevant literature and support arguments with evidence; and a presenter to summarize and report the group's findings. Each group was randomly assigned one of the four questions. The instructor then guided the groups through the relevant anatomy, functions, and clinical manifestations of the facial nerve.

Instructor guidance for each question included: (1) Understand the anatomical course and potential injury sites of the facial nerve. Analyze how damage at different anatomical segments may result in facial palsy. (2) Understand the motor, sensory, and parasympathetic functions of the facial nerve. Use anatomical knowledge to explain and predict the range of symptoms associated with facial nerve palsy. (3) Identify key anatomical regions for treatment planning in left-sided facial palsy. Facial nerve injury may occur in the intracranial, intratemporal, or extratemporal segments, and the prognosis and therapeutic priorities vary depending on the site of injury. (4) Peripheral facial paralysis is generally reversible in most cases, although recurrence may occur. During facial nerve regeneration and recovery, multiple anatomical factors can influence treatment outcomes. Recovery varies depending on the site of injury. Factors such as the integrity of facial nerve branches, the intrinsic regenerative capacity of the nerve, local blood supply, and the timing and method of intervention all play important roles in therapeutic effectiveness.

Students were guided to explore the latest medical frontiers in facial nerve research from two key perspectives: (1) Diagnosis and treatment of facial nerve disorders–Investigating how to achieve more accurate diagnoses and develop more effective treatment strategies. (2) Repair and regeneration of facial nerve injuries–Exploring approaches to enhance nerve repair and regeneration, with the goal of improving patient outcomes and quality of life. Group leaders coordinated collective discussions across all groups, identifying common issues and areas of special concern that emerged from the presentations. Recorders were responsible for summarizing key viewpoints and final conclusions, while group spokespersons delivered summary presentations on their respective group's discussion results.

Through this group-based analytical discussion, students developed a deeper understanding of the anatomical foundations, pathogenesis, diagnosis, and treatment strategies for left-sided facial nerve palsy. Additionally, the activity enhanced their teamwork, critical thinking, and problem-solving skills. During the teaching process, the instructor provided continuous guidance and concluded with a summary of frontier medical knowledge. Key topics included: RNA interference (RNAi) techniques to suppress the expression of specific inflammatory mediators and reduce neuroinflammation, thereby protecting the facial nerve from further damage; Nanotechnology-based drug delivery systems for targeted delivery and enhanced therapeutic efficacy; Gene therapy to promote facial nerve regeneration and functional recovery; Bioactive scaffolds combining growth factors and cells to support nerve regeneration and restore function.

Facial nerve research is expected to advance significantly in multiple areas. With the ongoing development of precision medicine, the diagnosis of facial nerve disorders will become increasingly accurate and individualized. Progress in cell biology, biomaterials science, and artificial intelligence will contribute to more precise diagnostic tools and personalized treatment plans. Furthermore, interdisciplinary integration between neuroscience and fields such as immunology and genetics will offer new perspectives and strategies for the prevention and management of facial nerve disorders.

2.3. Evaluation indicators

Student performance was assessed through experimental skill evaluations, case analysis reports, review writing, and a final examination to compare the outcomes of the teaching method that integrated cutting-edge medical knowledge into case-based learning. Clear scoring criteria were established, with assessments based on content accuracy, completeness, logical structure, and originality. These evaluations aimed to measure analytical abilities, problem-solving skills, and understanding of frontier medical knowledge.

2.4. Statistical analysis

Statistical analysis was conducted using SPSS version 24.0. Data were expressed as mean ± standard deviation. The independent samples t-test was used to compare differences between the two groups, with $P < 0.05$ considered statistically significant.

In addition, a questionnaire survey was designed to collect students' feedback on the effectiveness of the integrated frontier case-based teaching method compared to the traditional case-based approach. The questionnaire covered several aspects, including learning interest, motivation, knowledge acquisition, literature reading skills, and the development of clinical reasoning. The survey was conducted anonymously to ensure the authenticity and objectivity of student responses. Collected data were subjected to statistical analysis to summarize key feedback and suggestions from the students.

3. Results

Students in both the CBL group and the CBL with Medical Frontier Integration group were evaluated using four components: case analysis (10 points), clinical skills assessment (10 points), a neuroanatomy-related literature review (40 points), and a closed-book final examination (40 points). The scores and statistical results were presented in **Table 2**.

Table 2. Comparison of assessment scores between the two groups (mean ± SD) $*P < 0.05$, $**P < 0.01$ compared with the CBL group.

Group	Case Analysis (10 pts)	Clinical Skills (10 pts)	Review Writing (40 pts)	Final Exam (40 pts)	Total Score (100 pts)
CBL Group	6.91 ± 1.15	7.34 ± 0.86	31.44 ± 2.96	32.66 ± 2.85	78.34 ± 4.65
CBL with Medical Frontier Integration Group	7.90 ± 0.96**	7.88 ± 0.99*	33.68 ± 2.65**	34.38 ± 2.34**	83.83 ± 4.05**

The results indicate that the CBL with Medical Frontier Integration group showed significantly higher scores in case analysis compared to the CBL group, review writing, and mastery of theoretical knowledge, with statistically significant differences. These findings suggest that integrating cutting-edge medical knowledge into CBL can effectively guide students to explore the frontiers of the discipline, stimulate scientific curiosity and research interest, and foster a rigorous scientific mindset, innovative thinking, and creative capabilities. This approach also contributes to the comprehensive development of students' competencies.

A total of 72 questionnaires were distributed—32 to the CBL group (31 collected) and 40 to the CBL with Medical Frontier Integration group (all 40 collected). The results of the questionnaire survey are summarized in **Table 3**.

Table 3. Comparison of questionnaire survey results between the two groups (n, %).

Group	Increased Interest and Motivation	Enhanced Knowledge Acquisition and Application	Improved Clinical Reasoning and Research Skills	Improved Literature Reading Ability	Improved Review Writing Skills	Increased Learning Satisfaction
CBL Group	29 (93.5%)	28 (90.3%)	26 (83.9%)	20 (64.5%)	16 (51.6%)	26 (83.9%)
CBL with Medical Frontier Integration Group	38 (95.0%)	37 (92.5%)	37 (92.5%)	39 (97.5%)	37 (92.5%)	36 (90.0%)

The results demonstrate that the case-based teaching approach effectively integrates theoretical knowledge of neuroanatomy with clinical practice. Through the process of analyzing clinical cases, students developed a deeper understanding of anatomical structures, physiological functions, and pathological changes. Students expressed a high level of recognition and approval for the case-based teaching method integrated with cutting-edge medical knowledge. They reported that this approach enhanced both the engagement and practicality of learning, leading to greater overall satisfaction with the course. By incorporating frontier medical knowledge into case analyses, students were able to more intuitively appreciate the real-world applications of neuroanatomical concepts. This not only stimulated their curiosity and desire for knowledge, but also increased their interest and motivation to learn. As a result, students became more proactive in exploring and acquiring relevant content. Furthermore, the integration of current research advances encouraged students to develop an interest in scientific inquiry and guided them to stay informed about the latest developments in the field of neuroanatomy, thereby laying a strong foundation for their future research endeavors.

4. Discussion

Neuroanatomy is a highly specialized and complex discipline that involves intricate anatomical structures and abstract functional relationships. Traditional neuroanatomy instruction has predominantly relied on didactic lectures, where instructors deliver content and students passively absorb information. This conventional approach often lacks interactive elements, rendering the learning process monotonous and reducing student engagement and enthusiasm. Consequently, students are less likely to ask questions or engage in peer discussion, which limits deep understanding and impedes the application of theoretical knowledge to real-world clinical contexts [8,9]. With the ongoing advancement of medical technologies and evolving healthcare paradigms, medical education must also evolve through continuous innovation. As a promising pedagogical model, case-based learning (CBL) plays a pivotal role in promoting reform in medical education. The integration of cutting-edge neuroscience—one of the most rapidly advancing fields in modern medicine—into CBL not only enhances instructional relevance but also supports the translation of scientific progress into educational practice [10,11].

The deep integration of clinical case analysis with frontier medical knowledge allows students to engage with the latest discoveries and technologies, broadening their academic horizons and strengthening their knowledge foundation. This approach increases awareness of current trends in the medical field and promotes the dissemination and practical application of advanced concepts. Furthermore, it fosters interdisciplinary collaboration between basic science educators and clinical practitioners. While clinicians contribute authentic case materials, basic science instructors integrate these into theoretical frameworks, enhancing both the relevance and accessibility of course content. This collaborative teaching strategy makes learning more clinically meaningful and pedagogically engaging. Equally important, this approach emphasizes student-centered learning and active participation. It encourages learners to think critically, explore independently, and engage deeply with course materials—transforming them from passive recipients of information into active constructors of knowledge.

Neuroanatomy remains a core foundational course that plays a crucial role in shaping students' future performance in clinical and research contexts [12]. The application of CBL helps students bridge the gap between abstract anatomical theory and real-life clinical scenarios, improving the clarity, relevance, and applicability of the subject [13]. Building upon the CBL framework, the incorporation of cutting-edge medical research further enriches the curriculum and shifts the focus from passive knowledge acquisition to applied learning and inquiry-based exploration. In the study, multiple dimensions of teaching effectiveness—including literature review writing, case analysis, theoretical assessments, and student feedback—were comprehensively evaluated. Students in the CBL with the Medical Frontier Integration group demonstrated superior performance in mastering theoretical concepts, retrieving relevant literature, and composing scientific reviews. These findings underscore the effectiveness of this teaching model in fostering both clinical reasoning and research literacy. In addition, the questionnaire results revealed a higher level of student satisfaction in the integration group. The infusion of contemporary research made the course content more dynamic, relevant, and inspiring, thereby enhancing student motivation and engagement. This study thus proposes a neuroanatomy teaching model that integrates basic theoretical instruction, case-based analysis, and scientific inquiry, providing a well-rounded and progressive educational framework. The model improves teaching quality and helps cultivate medical professionals with both advanced scientific knowledge and strong clinical reasoning skills.

Nonetheless, this study has certain limitations. The relatively small sample size may limit the generalizability of the findings. Future studies should include larger and more diverse cohorts to obtain more representative and statistically robust conclusions. Additionally, due to constraints in instructional time and resources, it was not feasible to incorporate a broader range of complex clinical cases or to cover a more extensive spectrum of neurological conditions and medical frontier topics. This study primarily focused on short-term educational outcomes, without assessing students' long-term knowledge retention or practical skill application. Furthermore, given the rapid pace of advancement in neuroscience, instructors are required to engage in continuous professional development to keep teaching content scientifically accurate and pedagogically relevant. As medical science continues to evolve, more innovative technologies and frontier research will undoubtedly be integrated into medical education. Through continuous refinement and optimization of instructional methods, the quality of neuroanatomy education will be further enhanced—ultimately contributing to the development of medical professionals equipped with up-to-date scientific insight and robust clinical thinking abilities.

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Disclosure statement

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