2025 Volume 3, Issue 3
Lecture Notes in Education, Arts, Management and Social Science
ISSN(Online): 2705-053X

Exploration of the Application of Artificial Intelligence in Standardized Training of Laboratory Medicine Residents

Yuanyuan Dai[1,2], Nannan Cheng[1,2]*
[1]Center for Medical Laboratory Science, Affiliated Hospital of Youjiang Medical University for Nationalities , Baise 5330 00, Guangxi, China
[2]Key Laboratory of Research on Clinical Molecular Diagnosis for High Incidence Diseases in Western Guangxi of Guangxi Higher Education Institutions, Baise 533000, Guangxi, China

**Author to whom correspondence should be addressed.*

Abstract: With the rapid development of artificial intelligence technology, its application in the medical field is becoming increasingly widespread. Standardized training for residents in laboratory medicine is crucial for cultivating qualified talent in this field. This article explores the application of artificial intelligence in standardized training for residents in laboratory medicine, analyzes the opportunities and challenges it brings, and aims to provide new ideas and methods for improving training quality and effectiveness.

Keywords: Artificial intelligence; Laboratory medicine; Smart education; Talent cultivation

Online publication: April 26, 2025

1. Introduction

Artificial intelligence (AI) is a technology that uses computers to simulate human intelligence. Through algorithms such as machine learning, deep learning, and natural language processing, machines can automatically handle complex tasks, make decisions, and perform predictions. In recent years, artificial intelligence technology has made breakthroughs and demonstrated powerful capabilities in image recognition, data analysis, and other aspects. It is gradually penetrating various industry sectors, and the medical industry is no exception [1].

Laboratory medicine occupies a central position in the modern medical diagnosis and treatment system, providing indispensable objective evidence for clinical diagnosis, treatment monitoring, and prognosis evaluation. From routine blood and urine tests to complex genetic testing, the accuracy and efficiency of laboratory medicine directly affect medical quality. As a key link in cultivating professional talents in laboratory medicine, standardized training for residents aims to enable medical students to smoothly transition from theoretical learning to clinical practice and master solid professional skills and knowledge. However, the traditional training model exposes shortcomings such as insufficient flexibility and low personalization when facing the current massive and rapidly updating laboratory medicine knowledge, as well as complex and changing clinical testing scenarios.

The combination of artificial intelligence and standardized training for residents in laboratory medicine has great potential. On the one hand, artificial intelligence can integrate various laboratory medicine data, including test results, case information, and imaging, to build a rich digital resource library for training. Through virtual laboratory testing, intelligent simulated cases, and other forms, it provides residents with an immersive and repeated practice learning environment. On the other hand, with the powerful analytical capabilities of artificial intelligence algorithms, personalized learning programs can be tailored according to the learning progress and ability characteristics of residents, achieving precise teaching [2]. Simultaneously, the auxiliary diagnosis model constructed by artificial intelligence can help residents improve their ability to interpret test results and strengthen clinical diagnostic thinking. This combination is expected to break through the limitations of traditional training, innovate the standardized training model for residents in laboratory medicine, comprehensively improve training quality, and cultivate professional talents in laboratory medicine who are more adapted to modern medical needs.

2. Advantages of artificial intelligence in standardized training for residents in laboratory medicine

2.1. Enriching training resources

With its powerful data integration and processing capabilities, artificial intelligence can aggregate massive and dispersed data in the field of laboratory medicine. These data cover various test results, from routine blood and urine tests to complex genetic and immunohistochemistry tests. It also includes rich case materials containing detailed clinical cases of different disease types and stages. In addition, there are various imaging techniques such as ultrasound images and molecular images related to testing. Through deep mining and organization of these data, a comprehensive and dynamically updated digital training resource library is constructed.

In this resource library, virtual cases are presented in a highly simulated form. Residents can access virtual cases from different regions and hospitals with various complex conditions and testing features. For example, virtual cases for blood system diseases not only show patients' blood routine and bone marrow puncture test data but also simulate patients' medical history, symptom evolution, and changes in test indicators after treatment. Simultaneously, simulated test operation videos record the operation steps and precautions from sample collection, transportation, pretreatment, to various advanced test instrument operations. Taking the operation of an automatic biochemical analyzer as an example, the video will clearly show the entire process of instrument preheating, sample loading, parameter setting, detection process monitoring, and result reading, allowing residents to watch and learn repeatedly as if they were on the scene [3]. The virtual laboratory created using artificial intelligence technology is a major highlight. Here, residents can freely choose different types of testing instruments for virtual operation practice. Whether it is detecting cell surface markers with a flow cytometer or the complex operation process of a high-throughput gene sequencing instrument, it can be accurately simulated in a virtual environment. This learning model, which is not limited by time and space, greatly enriches residents' learning paths and allows them to quickly improve their operational skills through repeated practice.

2.2. Personalized learning support

Like an intelligent learning mentor, artificial intelligence algorithms can precisely track and analyze the entire learning process of resident physicians. They collect various data in real-time during their daily learning, including online course learning duration, answer accuracy, operational proficiency, and interaction behavior with the learning platform. Through deep mining and analysis of these multi-dimensional data, the intelligent system can accurately determine the current level of knowledge mastery and ability of resident physicians [4].

For example, when the system analyzes a resident physician's answering performance in a microbiology laboratory course and identifies frequent errors in topics related to Gram staining result interpretation, it immediately recognizes this knowledge point as a weak area. The system then automatically selects targeted learning content from its vast resource library for delivery. This content may include high-definition video courses that detail the principles of Gram staining, operational essentials, and result interpretation techniques, interspersed with numerous practical case studies to aid understanding. Additionally, the system pushes a series of practice questions related to Gram staining result interpretation, with difficulty levels progressing from basic to advanced. Each question is accompanied by detailed answer explanations to guide deep thinking and strengthen knowledge application. Based on feedback from the resident physicians, the system dynamically adjusts subsequent learning plans to ensure that the learning pathway always aligns with their personalized needs, truly implementing individualized teaching and significantly improving learning efficiency.

2.3. Intelligent assisted diagnosis training

In clinical laboratory practice, accurate interpretation of test results is a critical bridge between laboratory data and clinical diagnosis. Through deep learning of massive clinical case data, artificial intelligence constructs powerful intelligent assisted diagnosis models. These models integrate multiple test indicators, uncover potential correlations and patterns among them, and provide valuable references for disease diagnosis [5,6].

Taking the common diagnosis of diabetes as an example, the artificial intelligence system not only analyzes routine test indicators such as fasting blood glucose, postprandial blood glucose, and glycated hemoglobin but also considers relevant test data such as insulin release tests and C-peptide levels. By combining this information with clinical case data from a large number of diabetic patients, including age, gender, family history, symptoms, and other information, the system rapidly and accurately suggests the presence of diabetes and its possible type through complex algorithmic calculations. During training, resident physicians can use these intelligent assisted diagnosis models to analyze and interpret specific test results. By comparing their own diagnostic thinking with the model's suggestions, they can deeply consider the differences between them. For instance, if a resident physician initially suspects type 1 diabetes based on test results but the model suggests type 2 diabetes, the resident would further review relevant materials to understand the basis for the model's judgment, such as the patient's insulin secretion curve characteristics and physical features. Through this continuous process of comparison and learning, resident physicians can deepen their understanding of disease diagnosis, gradually master comprehensive and accurate methods of interpreting test results, and effectively improve their diagnostic abilities.

2.4. Improving training efficiency

In the traditional standardized training model for resident physicians in laboratory medicine, the instructor bears a heavy teaching load. From repeated explanations of basic knowledge to multiple demonstrations of laboratory operations, the instructor needs to spend a lot of time and energy on repetitive tasks. The introduction of artificial intelligence technology is like having a capable assistant for the instructor, which can share many teaching tasks.

The intelligent question answering system is one of them. It utilizes natural language processing technology to understand questions raised by resident physicians in real-time and quickly retrieves accurate answers from the knowledge base. Whether it is a question about testing principles, such as "What is the principle of double antibody sandwich method in ELISA?" or a confusion about testing operations, like "How long must samples be tested within after collection during blood gas analysis?," the intelligent question answering system can provide detailed answers in a timely manner. This significantly saves the instructor's time, allowing them to devote more energy to more targeted clinical practice guidance. Instructors can have more time to lead resident physicians to the forefront of clinical practice, participate in the testing and analysis of actual cases, and provide on-site guidance on issues such as interpretation of test results and selection of test items in complex conditions. At the same time, when facing complex problems encountered by resident physicians in clinical practice, instructors can use the saved time to discuss solutions to the problems more deeply with resident physicians, helping them improve their ability to solve practical problems, thereby comprehensively improving overall training efficiency.

3. Challenges faced by artificial intelligence in standardized training of resident physicians in laboratory medicine

3.1. Data quality and security issues

In the field of laboratory medicine, data sources are extremely wide-ranging, covering various medical institutions at different levels, testing instruments of different brands and models, and diversified sample collection methods. This complexity makes it difficult to ensure the accuracy, completeness, and consistency of data. For example, when different hospitals' testing instruments detect the same indicator, due to differences in calibration methods, detection principles, and reagents, there may be large deviations in the numerical results. Simultaneously, irregular operations during sample collection, such as inaccurate blood collection time, insufficient sample size, or contamination, can lead to incorrect or unreliable test data. In terms of data integrity, information systems in some medical institutions may have loopholes, resulting in missing key information in patient records, such as family history and complete treatment process records, which is extremely unfavorable for building a comprehensive and accurate artificial intelligence model.

Additionally, medical data involves a large amount of private information about patients, from basic personal identity information to detailed disease diagnosis and treatment records. Once leaked, it will severely infringe on the privacy rights of patients. In the data collection process, if there is no strict patient authorization process, there may be a risk of illegal data collection. As the amount of data continues to grow, the security of storage devices is tested. Situations such as hacker attacks or damage to data storage media may lead to data leakage or loss [7]. During data usage, the participation of multiple departments and personnel complicates data access rights management. If the permissions are not set properly, it can easily lead to data misuse. How to ensure reliable data quality and guarantee data security while fully utilizing laboratory medicine data to promote the development of artificial intelligence has become an important problem that needs to be solved urgently in the process of applying artificial intelligence to the standardized training of resident physicians in laboratory medicine.

3.2. Model reliability and interpretability

Although artificial intelligence models have demonstrated potential in assisting diagnostic tests in medical laboratories, many current models' decision-making processes resemble a "black box," lacking clear interpretability [8]. In the field of laboratory medicine, where accuracy and reliability are paramount, resident physicians find it difficult to trust a model whose decision-making basis they cannot understand. For instance, when certain deep learning models analyze complex genetic testing data to predict disease risks, they can quickly produce results but fail to articulate the specific genetic features and logical relationships upon which their judgments are based. This leads resident physicians to doubt the model's results and hesitate to use them as a strong basis for clinical diagnosis.

Moreover, the performance of these models is highly susceptible to various factors. Data bias is a common issue. If the dataset used to train the model contains a disproportionately high percentage of data related to a certain disease or feature, the model may overlearn that feature, leading to misjudgments in other scenarios. Disease heterogeneity also poses a significant challenge for the models. The same disease can manifest with vastly different clinical symptoms and laboratory test variations in different patients, and it is difficult for models to fully and accurately capture these differences [9]. Additionally, as medical technology continues to evolve, testing methods and standards are constantly changing. If the model is not updated and optimized in a timely manner, its reliability will be significantly reduced. Errors or deviations in the model during training or clinical practice can mislead resident physicians' learning and potentially have serious consequences for patient diagnosis and treatment.

3.3. Inadequate teaching faculty construction

The deep integration of artificial intelligence technology into the standardized training of resident physicians in laboratory medicine poses higher demands on mentors. Mentors need to not only be proficient in traditional laboratory medicine knowledge and skills but also possess a certain level of artificial intelligence knowledge and application ability. They should be able to skillfully guide resident physicians in the correct use of various artificial intelligence technologies and tools. However, most mentors in laboratory medicine currently have a relatively limited knowledge base in the field of artificial intelligence. They may have a superficial understanding of the principles of core artificial intelligence algorithms such as machine learning and deep learning, but they lack practical experience in building and optimizing artificial intelligence-assisted diagnostic models.

In terms of teaching methods, mentors often adhere to the traditional knowledge-based teaching model and lack the ability to integrate artificial intelligence technology with traditional teaching methods. For example, when explaining the interpretation of test results, it is difficult for them to use artificial intelligence models for vivid and intuitive demonstrations and analyses, thereby failing to fully utilize the advantages of artificial intelligence in enhancing teaching effectiveness [10]. This lag in teaching faculty construction severely limits the widespread application and in-depth promotion of artificial intelligence technology in the standardized training of resident physicians in laboratory medicine. Without timely strengthening of mentors' training and ability improvement in artificial intelligence, it will be difficult to meet the requirements of cultivating laboratory medicine talents who can adapt to the medical needs of the new era.

3.4. Adaptation of resident physicians to new technologies

Some resident physicians have long been exposed to traditional training models and have become accustomed to relatively fixed learning methods and knowledge acquisition pathways. They may have an instinctive aversion to the introduction of artificial intelligence technology as a new training model. They may fear that the new technology will increase the difficulty of learning, disrupt their original learning pace, and lead to poor learning outcomes. Moreover, the learning and application of artificial intelligence technology require resident physicians to have a certain foundation in computer science and data analysis. However, in reality, some resident physicians have a relatively weak foundation in this area and feel overwhelmed by complex artificial intelligence algorithms, data processing software, and the operation of intelligent learning platforms.

For example, when using intelligent assisted diagnostic models, some resident physicians may be unable to accurately interpret the results provided by the model due to unfamiliarity with its input and output rules. When participating in artificial intelligence-based virtual laboratory experiments, their unfamiliarity with the computer-simulated environment may lead to frequent errors during the experiment, affecting the learning experience and effectiveness. This inadaptation to new technologies often requires resident physicians to spend a significant amount of additional time and effort learning and exploring during the initial stages of training. This process may further exacerbate their aversion to artificial intelligence technology, which is not conducive to the smooth progress of artificial intelligence in the standardized training of resident physicians in laboratory medicine.

4. Coping strategies

4.1. Enhancing data management and security

To ensure data quality, it is necessary to establish a comprehensive and multi-level data quality control system. At the source of data collection, for medical institutions at various levels and types, uniform and strict standard operating procedures (SOPs) for sample collection should be developed. These SOPs should specify detailed specifications for the time nodes, operational techniques, and sample size requirements for various types of sample collections, such as blood and urine collections. Simultaneously, training and assessment of collection personnel should be strengthened to ensure operational standardization. For testing instruments of different brands and models, regular instrument calibration and comparison work should be carried out, and unified calibration reference standards should be established through third-party authoritative institutions to reduce deviations in test results between instruments. In the data entry process, advanced automatic data entry and verification technologies should be introduced, such as optical character recognition (OCR), to reduce manual entry errors. Multiple logical verification rules, such as numerical range verification and required field verification, should also be set to ensure the accuracy of entered data.

In terms of data security, advanced encryption technologies should be adopted to encrypt the collected medical data throughout the entire process. During data transmission, encryption protocols such as SSL/TLS should be used to prevent data theft or tampering. In the data storage phase, encrypted storage algorithms should be used to encrypt and store data, making it difficult to crack even if the storage medium is lost or attacked. At the same time, a comprehensive data access control system should be constructed for fine-grained management based on roles and permissions. For example, personnel roles can be divided into residents, teachers, data administrators, etc., and corresponding data access permissions can be assigned to different roles. Residents can only access anonymized case data related to their own training, teachers can access teaching data within a certain range, and data administrators have the highest level of data management permissions, but their operations are subject to audit tracking. Additionally, relevant laws and regulations, such as the Health Insurance Portability and Accountability Act (HIPAA), should be strictly followed to establish detailed data usage norms and clarify the legal and compliant processes for data collection, storage, sharing, and application, thus ensuring data security from the institutional level.

4.2. Improving model reliability and interpretability

Developing interpretable artificial intelligence models is key. On the one hand, visualization techniques can be used to intuitively present the decision-making process of the model. For example, in image-based testing models, heat maps can be used to showcase the key areas that the model focuses on when analyzing test images, allowing residents to clearly understand the basis of the model's judgments. On the other hand, knowledge graph technology can be utilized to combine medical knowledge with model decision logic, constructing an interpretable knowledge reasoning network. For analysis models of genetic testing data, the knowledge graph can clearly display the correlation paths and causal relationships between genes and diseases that the model relies on.

In terms of model validation and evaluation, a multi-center, large-scale clinical data validation platform should be established. By collaborating with medical institutions of different regions and sizes, diversified clinical case data can be collected to comprehensively test the model. Besides evaluating conventional indicators such as accuracy, sensitivity, and specificity, clinical practicality evaluation indicators should also be introduced, such as the degree of influence of the model on clinical decision-making and the impact on medical costs. The model should be regularly updated and optimized to timely incorporate new testing technology standards, disease diagnosis and treatment guidelines, and the latest clinical case data. For example, as novel coronavirus detection technologies continue to be updated, related artificial intelligence-assisted diagnosis models should be promptly optimized based on new detection methods and clinical features to ensure that the models maintain high reliability and clinical applicability.

4.3. Strengthening the construction of teaching staff

Develop a systematic and tiered AI training course system. Based on the different foundations of medical laboratory science teachers, offer introductory, intermediate, and advanced courses. The introductory course mainly introduces the basic concepts of AI, commonly used algorithm principles, and the current application status in the field of medical laboratory science, providing teachers with a preliminary understanding of AI. The intermediate course delves into the practical application of core algorithms such as machine learning and deep learning in medical laboratory data processing and auxiliary diagnosis model building. Through practical case analysis and operational drills, it enhances teachers' application abilities. The advanced course focuses on the latest research achievements and development trends of cutting-edge AI technologies in medical laboratory science, cultivating teachers' scientific research and innovation abilities.

Encourage teachers to actively participate in AI-related scientific research projects and teaching practices. Medical institutions and universities can establish special scientific research funds to support teachers in conducting research projects on AI-assisted medical laboratory science teaching. For example, studying how to utilize AI to optimize the teaching content and methods of medical laboratory science and improve teaching effectiveness. Simultaneously, organize teachers to participate in domestic and international academic exchange activities, facilitating communication and cooperation with experts and scholars in the field of AI, broadening their horizons, and learning from advanced experiences. Furthermore, invite senior experts in the field of AI to regularly give lectures and guidance to medical laboratory science teaching units, providing professional technical support and theoretical guidance to the teaching staff and accelerating the overall improvement of the teaching staff's level in AI.

4.4. Facilitating residents' adaptation to new technologies

Strengthen publicity and education work for residents in the early stages of training. Through special lectures, online courses, and other formats, introduce the application prospects, advantages, and positive impacts of AI technology in the field of medical laboratory science on their professional development to residents. For instance, demonstrate practical cases of AI-assisted diagnosis models improving diagnostic accuracy and reducing diagnostic time, allowing residents to recognize the value of new technologies, thereby changing their mindsets and actively embracing new technologies.

Develop a tiered teaching plan based on the varying computer and data analysis foundations of residents. For residents with weak foundations, offer introductory courses on basic computer skills and data analysis, providing systematic training from the basic use of computer operating systems, office software operations, to simple data statistical analysis methods. For residents with a certain foundation, provide advanced courses on AI technology applications, such as introductions to AI algorithm principles and advanced applications of intelligent learning platforms. In the initial stages of training, arrange for teachers to provide one-on-one or group guidance to residents. When using AI tools, teachers can demonstrate operational procedures on-site, answer questions, and help residents quickly get started. Simultaneously, establish study groups to encourage residents to exchange learning experiences, share operational tips, and collectively overcome difficulties encountered in adapting to new technologies. Gradually enhance residents' proficiency and application abilities in AI technology, ensuring the smooth implementation of AI in the standardized training of medical laboratory science residents.

5. Conclusion

AI technology has broad application prospects in the standardized training of medical laboratory science residents, offering numerous advantages such as enriching training resources, providing personalized learning support, assisting in diagnosis training, and improving training efficiency. However, its application also faces challenges such as data quality and security, model reliability and interpretability, inadequate teaching staff construction, and residents' adaptation. By adopting strategies such as strengthening data management and security, enhancing model reliability and interpretability, strengthening teaching staff construction, and promoting residents' adaptation to new technologies, we can effectively promote the application of AI in the standardized training of medical laboratory science residents, improve training quality, and lay a solid foundation for cultivating high-quality medical laboratory science professionals. In the future, with the continuous development and improvement of AI technology, its application in the standardized training of medical laboratory science residents will continue to expand and deepen, bringing new changes to the field of medical laboratory science education.

Disclosure statement

The authors declare no conflict of interest.

References

[1] Wiljer D, Hakim Z, 2019, Developing an Artificial Intelligence-Enabled Health Care Practice: Rewiring Health Care

Professions for Better Care. J Med Imaging Radiat Sci, 50(4 Suppl 2): S8–S14.

[2] Topol EJ, 2019, High-Performance Medicine: The Convergence of Human and Artificial Intelligence. Nat Med, 25(1): 44–56.

[3] Doherty I, Sharma N, Harbutt D, 2015, Contemporary and Future eLearning Trends in Medical Education. Med Teach, 37(1): 1–3.

[4] Borakati A, 2021, Evaluation of an International Medical E-Learning Course with Natural Language Processing and Machine Learning. BMC Med Educ, 21(1): 181.

[5] Chen D, Wang Y, Li Y, 2024, Discussion on the Application of Artificial Intelligence in Clinical Teaching for Medical Undergraduates. Smart Health, 10(13): 41–44.

[6] Pan G, Ye G, Fang S, et al., 2024, Ethical Exploration and Application of ChatGPT in Medical Clinical Practice. Chinese Journal of Thoracic and Cardiovascular Surgery, 31(6): 910–914.

[7] Ying M, Liu S, Chen X, et al., 2018, Medical Education in Transition: From the Information Age to Artificial Intelligence. Medical Education Research and Practice, 26(5): 721–723.

[8] Quinn TP, Jacobs S, Senadeera M, et al., 2022, The Three Ghosts of Medical AI: Can the Black-Box Present Deliver? Artif Intell Med, 124: 102158.

[9] Oladipupo T, 2010, Types of Machine Learning Algorithms. New Advances in Machine Learning, InTech, https://www.intechopen.com/chapters/10694

[10] Wahl B, Cossy-Gantner A, Germann S, et al., 2018, Artificial Intelligence (AI) and Global Health: How Can AI Contribute to Health in Resource-Poor Settings? BMJ Glob Health, 3(4): e000798.