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Current Situation and Reform of Tumor Radiotherapy Education: Integration and Innovation of Curriculum System, Practical Ability, and Intelligent Technology

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Abstract: This study systematically analyzes the current situation of tumor radiotherapy education and reveals the core contradictions it faces: lagging curriculum content, weak practical teaching, and insufficient interdisciplinary knowledge leading to deviations in clinical competence cultivation. Based on the current situation analysis, propose an innovative training model: (1) Curriculum reconstruction: Integrating OBE concept and ADDIE model, constructing a three-level curriculum system of "basic clinical frontier"; (2) Advanced Practice: Establishing a five level capability ladder using the EPA model (basic operations → conventional design → precise implementation → multidisciplinary integration → technological innovation), with supporting dynamic monitoring mechanisms; (3) Technological empowerment: Realizing clinical scene visualization training through digital twins, AI personalized learning systems, and VR/AR technology. The implementation path emphasizes the deep integration of intelligent technology, the incubation of clinical research projects, and the construction of a collaborative ecosystem between industry, academia, and research. The conclusion indicates that this model solves the lack of linkage between educational ecological elements, promotes the transformation of radiotherapy education towards "intelligence, personalization, and globalization," and provides a systematic solution for the strategic delivery of composite radiotherapy talents for a healthy China.
Keywords: Education in tumor radiotherapy; Innovative training mode; OBE-ADDIE curriculum system; EPAs competency advancement; Intelligent educational technology

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1. Introduction

Radiation therapy, as an important component of the comprehensive management of malignant tumors, has become an indispensable treatment method in clinical intervention. According to statistics, about 60% to 70% of cancer patients require radiation therapy during their disease progression [1]. In the three-level discipline system of clinical medicine in China, tumor radiotherapy, tumor surgery, and oncology together constitute the three pillars of tumor diagnosis and treatment. Its core value lies in relying on the biological effects of ionizing radiation to achieve precise destruction of tumor targets [2]. This discipline exhibits significant interdisciplinary integration characteristics. From a theoretical perspective, it is necessary to integrate multidimensional knowledge systems such as radiation physics, molecular biology, and medical imaging. From a practical perspective, it emphasizes the organic unity of clinical logical reasoning and precise technical execution [3]. As a highly specialized clinical course, its educational goal is to cultivate composite professionals with solid theoretical foundations, the ability to independently design personalized treatment plans, and the ability to prevent and control complications. The core teaching content covers key modules such as tumor pathology diagnosis, evidence-based evaluation of radiation therapy indications, individualized treatment plan development and implementation, aiming to promote the efficient transformation of multidisciplinary knowledge into clinical competence [4].

The report of the 20th National Congress of the Communist Party of China for the first time established "people's health" as a national strategic priority goal, emphasizing "placing the protection of people's health in a strategic position of priority development" [5]. This policy orientation not only promotes the deepening reform of the medical and health service system, but also puts forward systematic reconstruction requirements for the medical talent training mode. As a clinical specialty with high technological dependence and interdisciplinary characteristics, radiation therapy urgently needs to keep up with the times in its talent cultivation mode to respond to the urgent demand for comprehensive and innovative medical talents in clinical practice [6].

This article intends to systematically sort out the structural bottlenecks in China's current radiation therapy education system, deeply analyze their mechanisms, and propose a future-oriented training model reconstruction path, providing theoretical support and practical reference for the high-quality development of radiation therapy professionals.

2. Multidimensional analysis of the current status of radiation therapy training in medical education

2.1. Structural challenges in undergraduate education

In the undergraduate education system of clinical medicine in China, tumor radiotherapy has long been on the periphery, resulting in a serious lack of depth and breadth in its curriculum content and teaching practice. The educational dilemma is mainly reflected in three aspects: firstly, the updating of course content lags, still relying mainly on the traditional knowledge system of radiation physics, and failing to effectively integrate cutting-edge knowledge such as radiomics and radiogenomics. Secondly, the practical teaching process is weak, and the teaching process highly relies on the clinical experience of individual teachers, lacking a unified standardized case library and ability assessment system. Thirdly, the design of the assessment mechanism is single, still focusing on memory-based knowledge testing, neglecting the systematic evaluation of students' clinical reasoning, decision-making ability, and technological innovation potential [7]. Due to the aforementioned shortcomings, students' knowledge structure exhibits fragmented characteristics, making it difficult to construct a systematic clinical thinking system. Some medical colleges have taken the lead in carrying out teaching reform pilot projects, attempting to integrate flipped classroom and problem-based learning (PBL) methods [8]. Through the construction of virtual simulation laboratories and the introduction of artificial intelligence-assisted teaching systems [9,10], the interactivity and effectiveness of teaching have been improved to a certain extent, providing a reference path for subsequent reforms.

2.2. Transformation challenges of graduate education

Due to the educational gap at the undergraduate level, graduate students majoring in tumor radiotherapy generally face the dilemma of starting from a "zero foundation." This educational gap prolongs the formation cycle of professional abilities and also puts higher demands on the curriculum design and practical training at the graduate level [11]. Although standardized training for resident physicians has played a certain role in improving clinical skills, the current textbook system generally lags: it fails to integrate emerging technologies such as radiomics analysis and adaptive radiotherapy promptly [12]. This deficiency forces graduate students to rely on unstructured knowledge acquisition pathways, resulting in a significant gap between theoretical learning and clinical application, seriously restricting the development of their scientific research and innovation abilities, reflecting the systematic deficiencies of the current training mechanism in knowledge updating, skill transformation, and ability evaluation.

2.3. Analysis of structural contradictions

The shortage of radiation therapy professionals is not only due to insufficient educational coverage, but also closely related to the high threshold training requirements determined by their professional characteristics. From the perspective of epidemiology, the incidence rate of cancer continues to rise, which makes the demand for radiotherapy talents continue to expand, and the teaching content of radiotherapy in undergraduate education and clinical practice is obviously insufficient; At the level of professional characteristics, the cultivation of qualified talents requires a systematic training cycle of 3-5 years, and the existing education structure is difficult to meet this demand. There are two structural contradictions in the current education system: (1) The systematic disconnection between theory and practice, and the significant temporal and spatial separation between knowledge transmission and clinical scenarios. The traditional curriculum system keeps theoretical cognition at the level of abstract concepts and cannot support complex clinical decision-making needs. The assessment mechanism overly focuses on knowledge reproduction ability and neglects the effective evaluation of clinical thinking ability, resulting in a significant deviation between educational output and job competency requirements; (2) The curriculum system lacks interdisciplinary integration and follows a linear logic of "foundation clinical specialty." The teacher's background is single, making it difficult for students to establish a comprehensive understanding of the radiotherapy technology system. Clinical skills training is limited within the radiotherapy department and has not established a collaborative training mechanism with multiple disciplines, such as oncology, surgery and internal medicine, which cannot meet the practical needs of modern medicine for multidisciplinary diagnosis and treatment (MDT).

These structural contradictions reveal that the systematic reconstruction of radiation therapy education is imperative. The reform of radiation therapy education needs to go beyond local improvement paths and establish a comprehensive education ecosystem that deeply integrates theory and practice and cross-disciplinary linkage through the reconstruction of the "interdisciplinary clinical integration technological innovation" training system, in order to cultivate high-level talents who can truly meet future medical challenges.

3. Construction of an innovative training mode

3.1. Curriculum system paradigm reconstruction

Result-oriented education is a student-centered teaching method, first established as a core concept by American educator Spady in the 1990s. The ADDIE model (Analysis Design Development Implementation Evaluation) is a structured approach that helps teachers effectively set teaching objectives and evaluate learning outcomes. It determines teaching objectives through a structured approach, by determining what to learn, how to learn, and how to determine if learners have achieved learning outcomes, to assist teachers in implementing effective teaching. OBE focuses on the achievement of students' ultimate competence, emphasizing the development of teaching objectives based on what they can do. The ADDIE model provides clear process support and strengthens the structured organization of teaching content and methods. In the theoretical curriculum system of radiation therapy, based on the integration framework of Outcome-Based Education (OBE) and ADDIE model, the ultimate goal is to master the basic theory of radiation therapy, integrate multidisciplinary knowledge systems, and achieve the core competence of radiation oncologists. The three-level curriculum modules of radiation therapy are constructed with "basic clinical frontier", corresponding to three types of educational objectives: knowledge integration, clinical ability cultivation, and innovative expansion:

(1) Basic stage curriculum architecture: Focusing on the theoretical cornerstone of radiation therapy, focusing on integrating multidisciplinary basic knowledge. The curriculum includes Introduction to Radiobiology, Medical Imaging Anatomy, Radiotherapy Physics, and AI, guiding students to understand the interdisciplinary logic from radiation effect mechanisms to imaging and dose calculation. The teaching method should adopt a modular

design, promote cognitive integration through embedding real cases and problem-driven learning. Highlight the construction of "knowledge networking." Through contextualized case teaching, students can understand the connection between radiobiological effects and therapeutic mechanisms, and construct a systematic knowledge framework from molecular mechanisms to dose delivery.

(2) Clinical stage competency development: Focusing on the improvement of clinical competence, the course introduces a "clinical decision tree" orientation, with typical cases as the main line, covering the complete clinical process from treatment indication evaluation, scheme formulation, target area delineation to dose verification, including indication evaluation, target area delineation, plan design, and efficacy feedback. Cooperate with virtual simulation platforms and AI-assisted training systems to achieve interactive training for students in near-real scenarios, improving clinical judgment and operational proficiency.

(3) Frontier stage innovation expansion: Focus on the integration and improvement of cutting-edge technology and humanistic literacy. The course covers modules such as radiomics, biological dose prediction, clinical ethics, and technical risk assessment. Combining ethics, communication skills, and medical humanities courses, it promotes the cultivation of critical thinking, moral judgment, and collaborative spirit. Strengthen their doctor-patient communication skills and humanistic awareness through ethical decision-making sand tables, role-playing, and other situational simulations.

3.2. Advanced construction of practical teaching system

The Entrustable Professional Activities (EPAs) education model, established by Professor Ten Cate's team in the early 21st century, deconstructs complex clinical work into a series of specific, observable, and assessable behavioral units. Through detailed evaluation criteria and feedback mechanisms, it effectively improves the clinical competence and professional ethics of resident physicians. Research has shown that a diversified teaching program designed based on the six-dimensional competency model of "professional knowledge, clinical skills, communication skills, teamwork, research ability, and professional ethics" constructed based on EPAs significantly improves the comprehensive abilities of resident physicians compared to traditional training methods that combine learning and rotational practice. In the field of radiotherapy, a "5-level advanced system" has been constructed based on practical abilities, scientific research innovation, and interdisciplinary cooperation, combining EPAs with the actual clinical needs in China. It covers basic operations, conventional treatment, precision radiotherapy, interdisciplinary integration, and technological innovation.

The first stage is the basic operational level, emphasizing the standard operation of radiotherapy equipment, the standardized execution of treatment processes, and training in radiation safety knowledge and management processes. The focus is on mastering the usage norms of radiotherapy equipment, radiation safety protection, and operational process standards to ensure preliminary competence in routine treatment room operations. The second stage is the ability to design conventional plans, including the development of three-dimensional conformal radiotherapy plans, dose distribution optimization, and basic quality control skills, to enhance the ability to develop treatment plans for three-dimensional conformal radiotherapy and conventional IMRT, and to learn to independently complete target segmentation, dose calculation, and plan evaluation. The third stage involves precise radiotherapy capabilities, where the system masters the application and quality control methods of high-precision technologies such as IGRT, SBRT, and adaptive radiotherapy, and achieves precise implementation and adjustment through real case simulations, such as the operation and quality control of IGRT, adaptive radiotherapy, and SBRT. In the fourth stage, the study will expand the cultivation of interdisciplinary collaborative abilities, combine MDT simulation exercises to train students to propose reasonable treatment suggestions in interdisciplinary contexts, promote collaborative work between students and departments such as oncology, surgery, and imaging, and enhance their ability to design personalized treatment plans through interdisciplinary collaboration. The fifth stage is technological innovation capability, including AI assisted program design, radiomics analysis, and feasibility assessment of new technologies. Students are encouraged to identify technical bottlenecks during clinical training, carry out small-scale scientific research projects, explore research directions such as AI-assisted therapy and radiomics modeling, and enhance their innovation awareness and transformation ability.

4. Implementation path and safeguard measures

4.1. Intelligent technology empowers educational innovation

Faced with the rapidly developing trend of radiation therapy technology, traditional teaching models are no longer able to meet the requirements of modern education for refinement, visualization, and interactivity, as well as the practical needs of future medical talent cultivation. Therefore, it is necessary to actively introduce intelligent technological means, adapt to the trend of deep integration of technology and education, and construct a new teaching paradigm of "technology-driven virtual real integration". Among them, digital twin technology can achieve precise modeling of clinical equipment and processes in virtual space, create a virtual training environment that can be operated repeatedly and provide feedback in real-time, significantly improve teaching safety and efficiency, and achieve full process visualization training from case input, target area delineation to dose distribution. Artificial intelligence technology can be used to construct personalized learning paths. By analyzing students' learning behavior data through deep learning models, real-time recognition of knowledge mastery blind spots, and providing accurate learning feedback based on intelligent recommendation systems, a precise teaching path is constructed to improve learning efficiency and pertinence. In addition, virtual reality (VR) and augmented reality (AR) technologies can be used to simulate complex radiotherapy operation scenarios into interactive training modules, allowing students to complete practical exercises of complex skills such as target area delineation and dose distribution regulation in a risk-free environment, reducing the risk of novice misoperation and improving training effectiveness. Furthermore, a dynamic treatment model can be constructed by combining real patient data to promote the visualization and deduction of dose distribution and biological effects. Students can enhance their clinical adaptability through the full process training of "simulated reception treatment decision-making scheme formulation efficacy feedback", and help students understand the application of biological effects in individual treatment.

4.2. Student development support system

Build a student-centered "ability development transformation" closed-loop support system to promote the transformation of medical students from passive learners to active knowledge constructors. Firstly, implement a multidimensional competency assessment system that covers core dimensions such as professional knowledge, clinical skills, scientific research ability, communication and collaboration, and ethical judgment. Based on the assessment results, customize personalized training paths for students. Secondly, establish a "scientific research clinical" integrated platform, and through project-based training during the clinical rotation period, require students to start from actual clinical problems and complete a complete research path from mechanism exploration to technology transformation. Encourage them to design and implement technological innovation solutions based on actual clinical needs to enhance their research thinking and problem-solving abilities. Ultimately, an excellent project incubation mechanism will be established by setting up a "Hospital Innovation Workshop" to provide seed funding, mentor resources, and technical transformation support for high-potential projects, accelerate the implementation of results, and stimulate students' innovative vitality and professional identity.

4.3. Collaborative evolution of the education ecosystem

The system needs to break away from the closed operation mode of the traditional medical education system and shift towards an open education ecosystem with multi-party collaboration. The specific path includes: in terms of the integration mechanism of industry, academia, and research, co-building teaching, research, and development integrated laboratories with high-end medical equipment manufacturing enterprises, and promoting the integration path of "demand technology product." By incorporating frontline clinical needs into the R&D process of enterprises, we aim to enhance students' engineering thinking and technical application abilities. At the level of the education feedback system, establish a medical education innovation fund to return a portion of the profits from the transformation of medical research achievements to the education sector for talent cultivation and teaching reform, forming a virtuous cycle of “research transformation education.” Strengthening the embedding mechanism of social responsibility in the empowerment process of social responsibility: integrating public health science popularization into radiotherapy teaching content, organizing students to participate in community tumor screening and health education practices, enhancing their sense of professional mission and social responsibility, improving the public’s impression of “radiation damage” in radiotherapy, and creating a social public opinion environment conducive to the development of the discipline.

5. Conclusion

This study systematically identifies the structural barriers in the current education system for tumor radiotherapy, pointing out multiple bottlenecks such as outdated course content, weak practical links, and incomplete ability evaluation mechanisms. It reveals that the lack of linkage mechanisms between elements in the education ecosystem is the fundamental reason for the deviation in clinical competence cultivation. The current education ecosystem has failed to achieve organic linkage between teaching elements, resulting in a gap between students’ theoretical cognition, skill mastery, and innovation ability, which makes it difficult to meet the needs of the era of precision medicine and interdisciplinary integration development. On this basis, this article proposes an innovative training model with “curriculum system reconstruction-practical ability advancement-technology integration driven” as the core. This model takes ability orientation as the core and intelligent means as tools to promote the transformation of teaching from “knowledge imparting” to “competence cultivation.” It strives to build a composite education system that integrates multidisciplinary knowledge, enhances practical ability, and technology innovation orientation, providing theoretical support and operational path for the high-quality development of radiation therapy professionals in the new era.

Overall, the education of tumor radiotherapy is undergoing a deep transformation from “traditional indoctrination” to “intelligent empowerment.” The innovative training path constructed by our research institute is closely aligned with the national strategic goal of “Healthy China 2030” in strategic logic, and is in line with the development trend of new medicine in educational practice. We are committed to cultivating new era radiotherapy experts with technical capabilities, clinical thinking, and a humanistic spirit, and continuously injecting high-quality talent into China’s cancer prevention and treatment industry.

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