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Innovative Research on the Grassroots Cancer Prevention and Control System in China Based on Artificial Intelligence Exploring Technology Empowerment and Standardization Pathways

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Abstract: ***Under the steady advancement of the "Healthy China 2030" strategy, grassroots cancer prevention and control still face multiple challenges, including a shortage of medical resources, low coverage of health education, insufficient capacity for early cancer screening, and a lack of standardized diagnosis and treatment protocols. To address these challenges, this paper proposes leveraging technology empowerment and optimizing standardization pathways to promote the application of artificial intelligence (AI) in personalized health education, enhance the adoption of early screening technologies, and advance the standardization of diagnosis and treatment. These measures aim to facilitate the sharing of grassroots medical resources and narrow the urban-rural healthcare gap. Future development will focus on precision medicine and personalized treatment, utilizing genetic data and multimodal analysis to develop individualized treatment plans for patients. Additionally, the "unmanned hospital" model will be explored, where AI-driven automation in screening, sample management, and treatment processes is employed to alleviate resource shortages at the grassroots level. This study aims to provide innovative ideas and solutions for improving the grassroots cancer prevention and control system.***

Keywords: Artificial Intelligence, Grassroots Healthcare, Early Cancer Screening, Medical Standardization**.**

1. Introduction

Malignant tumors have become a major public health issue posing a serious threat to the health of Chinese residents. According to the latest data from the Global Cancer Report, in 2022, there were approximately 4.8247 million new cases of malignant tumors in China, with an incidence rate of 201.61 per 100,000 and a mortality rate of 96.47 per 100,000 [1]. Malignant tumors have a high disability rate, significantly reducing patients' quality of life. Meanwhile, studies have shown that the annual medical expenses caused by malignant tumors exceed 220 billion yuan, placing a heavy economic burden on China [2].

To effectively halt the progression of cancer and improve patient survival rates, since 2005, China has launched projects such as the "Huai River Basin Early Cancer Diagnosis and Treatment," "Grassroots Women's 'Two Cancers' Screening," and "Urban Early Cancer Diagnosis and Treatment." These initiatives have promoted cancer prevention and early treatment at the grassroots level, establishing a three-dimensional, multi-level cancer prevention and early treatment service system supported by grassroots medical institutions, from the central to local levels. With the implementation of these public welfare projects, the coverage of cancer prevention and treatment in China has expanded year by year, significantly improving the five-year survival rate of cancer patients and generating positive health, economic, and social benefits [3].

As China continues to deepen its healthcare support policies for grassroots areas, issues such as shortages in human resources, weak cancer prevention capabilities among residents, limited early screening capacity of medical institutions, and insufficient standardization in cancer diagnosis and treatment have been addressed to a certain extent. However, significant disparities remain compared to urban areas, and these challenges are still unable to fully meet the growing health needs of grassroots residents.

The application of artificial intelligence (AI) technology is expected to address many challenges in the field of cancer prevention and control in rural China, promoting the high-quality development of cancer prevention and control efforts. By integrating medical data and leveraging AI and big data analytics, high-risk groups for cancer in grassroots areas can be effectively identified and subjected to early screening. This approach reduces the time from suspicion to diagnosis, enhances diagnostic accuracy, and provides patients with more opportunities for timely treatment [4]. Additionally, AI can break down information barriers between regions and institutions, enabling the efficient integration and sharing of healthcare services [5]. This allows grassroots patients to access high-quality specialist diagnostic recommendations, effectively narrowing the gap in healthcare service levels between urban and rural areas.

This study focuses on the innovative research of a grassroots cancer prevention and control system based on artificial intelligence. By empowering technology and exploring standardized pathways, the study aims to enhance grassroots cancer prevention and control capabilities, optimize diagnostic and treatment processes, promote the sharing of medical resources, and reduce the urban-rural healthcare disparity. The ultimate goal is to provide new ideas and solutions for advancing the high-quality development of cancer prevention and control work in China's grassroots regions.

2. The Dilemmas in Cancer Prevention and Control in Grassroots Areas

2.1 Shortage of Human Resources and Bottlenecks in Capabilities for Cancer Prevention and Control at the Grassroots Level

At present, grass-roots medical institutions in China generally face problems such as heavy workloads for doctors and the inability of their professional levels to meet the requirements of cancer prevention and control. Statistical data shows that from 2011 to 2021, the annual number of outpatient and inpatient visits in township health centers across the country increased from 866 million to 1.161 billion, with an average annual growth rate of 2.97%. While undertaking basic medical responsibilities, grass-roots medical staff also need to be involved in cancer prevention and treatment work, resulting in a significant increase in their workloads. According to the "Statistical Communique on the Development of China's Health Care Cause in 2019", the input intensity of medical and nursing human resources for cancer prevention positions in rural areas is only 1.38 people per 10,000 service population, far lower than the WHO-recommended standard of 2.5 people per 10,000. The shortage of medical staff is an important reason restricting the smooth progress of cancer prevention and control work in China. Less investment in human resources makes it difficult to ensure the quality of cancer treatment.

On the other hand, due to the lack of grass-roots health resources, the professional qualities and skills of medical staff cannot meet the requirements of cancer prevention and treatment. Moreover, the training cycle for doctors is relatively long, and most high-quality doctor resources are concentrated in urban areas. According to the statistics in the "China Health Statistics Yearbook 2022", among the professional and technical talents in grass-roots medical institutions in 2021, only 44.0% had a college degree or above, and only 24.0% of the doctors in rural grass-roots hospitals had such degrees [6]. At present, the shortage of technical talents in cancer prevention and treatment in China restricts the further development of the capacity for cancer prevention and control at the grass-roots level. Although some places have already started relevant training on cancer prevention and treatment, such one-off training cannot fundamentally achieve effective improvement and is difficult to promote the sustainable development of talents for cancer prevention and control at the grass-roots level.

2.2 Insufficient Efficacy of Health Education: Dilemmas of Coverage and Dissemination Modes

The World Health Organization points out that if cancer-related risk factors can be controlled, one-third of cancers can be prevented; if detected early, two-thirds of cancers can prolong patients' lifespan, improve the quality of life or even be cured through treatment [7]. However, in China, there are still significant gaps in residents' awareness of malignant tumors. There is generally a lack of understanding of the harm, risk factors and early symptoms of malignant tumors, and residents' ability to prevent cancer is weak. Abroad, health education has become the preferred strategy to improve residents' ability to prevent cancer because of its relatively low input cost and obvious effects. The Chinese government attaches great importance to tumor health education and has successively introduced a number of policies, including the "Outline for China's Cancer Prevention and Control Plan (2004 - 2010)" and the "Healthy China 2030 Planning Outline". These policies all emphasize the concept of "prevention first and combining prevention with treatment", and have achieved remarkable results in improving residents' health literacy, enabling the level of residents' health literacy to maintain a relatively rapid growth rate. According to data from the Chinese Anti-Cancer Association and the National Health Commission, the health literacy level of urban and rural residents in China in 2024 is 31.87%, and the awareness rate of core knowledge of cancer prevention and control reaches 70.01%.

However, the coverage rate of tumor health education in grass-roots areas remains at a relatively low level. Despite policy promotion and strong government support, the actual coverage effectiveness is restricted by multiple factors: First, grass-roots areas have difficulty in carrying out systematic publicity and education activities due to shortage of funds, lack of professionals and insufficient technical training, resulting in obvious "blind spots" in the dissemination of health knowledge; Second, the limitations of traditional publicity and education models are significant. Relying on offline lectures, paper materials and other "point-to-point" dissemination methods, it is difficult to break through geographical restrictions, especially with insufficient coverage of the floating population; Third, the implementation of policies is fragmented. Although some regions have been included in the framework of the "Healthy China" initiative, there is a lack of unified technical specifications and assessment mechanisms, and the standardization level of publicity and education content is low, resulting in the core cancer prevention knowledge not effectively reaching the whole population. These multi-dimensional implementation bottlenecks have led to a continuous low operation of the coverage rate of grass-roots health education (less than 45% in rural areas in 2024), making it difficult to control cancer risk factors and achieve the goal of cancer prevention.

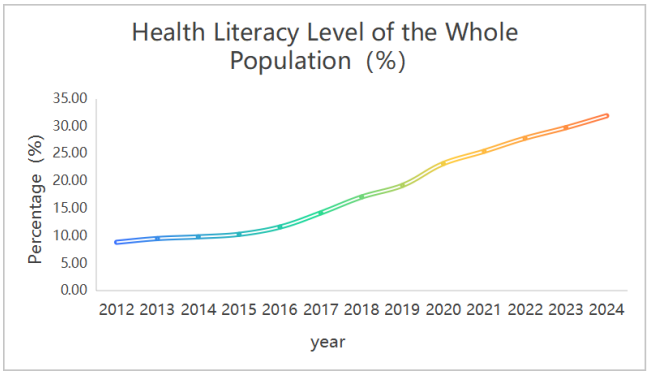

Figure 1: The level of health literacy among the general public

2.3 Difficulties in the Implementation of Cancer Screening and Early Diagnosis and Treatment at the Grassroots Level

Early diagnosis and treatment are not only the most effective means of fighting cancer but also can reduce the economic

expenditure on cancer diseases. Research shows that due to early diagnosis and treatment, tobacco control and the improvement of diagnosis and treatment technologies, the cancer mortality rate in the United States has been continuously declining from 1991 to 2018, with a total decrease of 31%, avoiding 3.2 million deaths from cancer [8]. However, at present, the cancer epidemic in China is characterized by the coexistence of cancer spectra of developed and developing countries, large urban-rural differences and uneven regional distribution. Moreover, the cancer prevention and control system in grass-roots areas in China is not yet mature, medical resources are scarce, the coverage of cancer screening is relatively limited, there are mismatches in the supporting professional hardware facilities of medical units related to cancer screening at all levels, there are gaps between the professional and technical capabilities of medical staff and the requirements of standardized diagnosis and treatment, and there are still significant gaps in residents' awareness of malignant tumors. Generally, residents have insufficient understanding of the harm, risk factors and early symptoms of malignant tumors, resulting in a low participation rate in cancer screening, unsatisfactory screening results, and the overall health effects of early diagnosis and treatment among the population have not been fully demonstrated.

2.4 The Lack of Standardization and Homogeneity in Cancer Diagnosis and Treatment at the Grassroots Level

At present, China's cancer prevention and control system is not yet perfect. There is a lack of unified prevention and treatment norms covering the whole country, and a systematic and objective evaluation mechanism for cancer prevention and control plans has not been established. There are problems such as inconsistent standards and lack of norms in the implementation of policies. Especially in grass-roots areas, the data management and sharing mechanism is relatively weak and lacks unified normative support. This not only leads to low prevention and control efficiency and uneven service quality, but also increases the cost of cancer prevention and control and the pressure on medical institutions.

In terms of diagnosis and treatment practice, in grass-roots areas, a fixed screening process is often adopted, in which a risk factor questionnaire is used for initial screening, imaging and endoscopic examinations are used for triage, and pathological diagnosis is carried out. Among them, the self-filled questionnaire method has the risk of data deviation and also consumes a large amount of human resources. At the same time, high-quality medical imaging, endoscopic and pathological diagnosis require high professional experience. The differences in the years of service and experience of medical staff significantly affect the diagnosis results, resulting in a non-negligible misdiagnosis and missed diagnosis rate. Taking the screening of female breast cancer in Beijing from 2011 to 2018 as an example, the coincidence rate between breast ultrasound and histological diagnosis was only 52.13%, and the missed detection rate reached 11.89% [9]. Therefore, the work of cancer diagnosis and treatment at the grass-roots level has a weak foundation in standardization and homogeneity. Relying on the traditional model is difficult to meet the actual needs of early diagnosis and early treatment. It is urgent to construct a cancer prevention and control system with unified standards, standardized processes and controllable quality.

3. Countermeasures of Artificial Intelligence in Cancer Prevention and Control in Grassroots Areas

3.1 The Assistance of Artificial Intelligence to Human Resources in Cancer Prevention and Control in Grassroots Areas

During the implementation of the family doctor contracting system and the hierarchical medical system, the work responsibilities of doctors have been continuously expanding. To reduce the workload of medical staff and improve their diagnostic capabilities, artificial intelligence is utilized to integrate information systems with residents' electronic health records, electronic medical records, health tracking devices, etc. This enables the automated collection of residents' health data, freeing medical staff from tedious questionnaires. Moreover, through the analysis of health medical big data and the application of deep learning technology, high-quality diagnosis and treatment for patients can be achieved, reducing the number of patient visits, alleviating patients' burdens, and enhancing the effectiveness and accessibility of cancer prevention and control at the grassroots level.

3.2 An AI-driven Personalized Health Education Model

The coverage rate of health education in grassroots areas of China is low. Traditional health education methods have problems such as insufficient breadth and depth, and high costs. Therefore, it is particularly urgent to integrate them with the Internet and artificial intelligence technologies to establish a new health education model. The combination of data algorithms and artificial intelligence can analyze massive amounts of data, helping hospitals understand the needs and preferences of the audience, thereby optimizing the dissemination content and improving technological levels. Through the WeChat official account platform, combined with technologies such as language decomposition and semantic understanding, hospitals can create a professional tumor health knowledge graph and accurately push personalized prevention and treatment information. In addition, online classes can be utilized for online exchanges with doctors. Health knowledge quizzes with prizes can be held on health days to increase residents' participation and improve the effectiveness of health education. This "Internet + artificial intelligence" health education model can not only reduce costs and break through geographical limitations, but also better adapt to the fragmented learning habits of contemporary people, increase the coverage rate of health education, improve residents' health quality and cancer prevention capabilities, and reduce the incidence of cancer.

3.3 Application of Artificial Intelligence in Early Screening and Diagnosis of Cancer

In cancer diagnosis and treatment, early screening, early diagnosis, and early treatment are the key links to improve the cure rate and reduce the mortality rate. With the rapid development of molecular biology and digital technologies,

artificial intelligence is gradually integrating into the research of tumor markers and the clinical screening system, showing vital value in multi-dimensional data integration, cancer risk prediction, and assisting doctors in diagnosis. Nowadays, the rapid accumulation of multi-omics data such as genomics, transcriptomics, proteomics, and metabolomics can reveal a panoramic view of tumorigenesis and development from multiple dimensions. However, their characteristics of high dimensionality, strong heterogeneity, and dynamic changes pose huge challenges to traditional analytical methods [10].

Artificial intelligence, especially machine learning and deep learning technologies, provide new ideas for tumor marker screening and risk prediction through their powerful model recognition and feature extraction capabilities. The new generation of artificial intelligence systems represented by large models has the ability to process multi-modal information such as electronic medical records, imaging reports, and test data, and has been widely applied in the early screening practice of various high-incidence diseases such as lung cancer, gastric cancer, and colorectal cancer. Related systems not only introduce the internationally accepted RADS grading system and high-risk screening criteria formulated based on the experience of clinical experts but also construct standardized datasets covering multiple tumor types. Through reasoning chain training, knowledge graph fusion, and RAG (retrieval-augmented generation) technology, traceability and interpretability in the model decision-making process are achieved. Research led by Professor Bai Chunxue shows that the non-invasive pathological diagnosis system and saliva metabolic feature model based on deep learning algorithms have achieved remarkable results in the early identification of lung adenocarcinoma and small pulmonary nodules. These explorations have promoted the step-by-step transition of intelligent early screening tools from scientific research to clinical practice, providing a more feasible and accessible technological empowerment path for grass-roots screening.

3.4 Artificial Intelligence Promotes the Standardization and Normalization of Cancer Prevention and Control

Artificial intelligence plays a very important role in the standardization of cancer prevention and treatment. Through in-depth mining and utilization of medical data, it explores guidelines suitable for malignant tumor prevention and control among grass-roots populations and high-risk groups, thus formulating a complete and unified cancer prevention and treatment plan, providing a scientific basis for personalized cancer prevention and treatment.

Based on artificial intelligence, remote expert online consultations, personalized health management, and professional skill training for telemedicine can also be achieved, improving the management and service levels of medical staff in grass-roots areas. At the same time, by introducing artificial intelligence technology, a "resident-centered" closed-loop management can be realized, improving the basic system of cancer prevention and treatment, realizing full-process services for cancer prevention and treatment, strengthening functions such as remote assessment, appointment referral, and follow-up after treatment, and gradually promoting the interconnection of relevant materials such as cancer prevention and control, residents' electronic health records, electronic medical records, tumor types, and causes of death, thus achieving the standardization and normalization of cancer prevention and treatment in grass-roots areas.

4. Future Development Directions

4.1 Precision Medicine and Personalized Treatment

Through artificial intelligence, doctors can conduct in-depth analyses of patients' genetic characteristics, disease progression, genetic data and other information, develop personalized diagnosis and treatment plans for patients, and predict patients' responses to different treatments, thereby reducing the risks associated with overtreatment or undertreatment. Based on deep learning algorithms, artificial intelligence can analyze massive multimodal data such as medical images, genomic data, and electronic medical records, providing personalized treatment plans for grassroots cancer patients and significantly improving treatment outcomes and survival rates. For example, by analyzing the genomic data of lung cancer patients using deep learning algorithms, it is possible to predict patients' sensitivity to EGFR inhibitors or PD-1 immune checkpoint inhibitors, providing a scientific basis for the clinical medication of lung cancer [11].

In addition, relying on large-scale clinical databases, artificial intelligence can identify the different efficacies of different treatment regimens for specific patient groups and predict patients' responses to different treatments. This helps clinicians use drugs rationally and administer them appropriately, reducing the harm caused by insufficient or excessive medication, treating patients more precisely, and fully leveraging the advantages and feasibility of artificial intelligence in medicine. In the treatment of breast cancer, through analyzing patients' hormone receptor status, gene expression profiles, and treatment response data, artificial intelligence can recommend the most suitable chemotherapy or endocrine treatment regimens, reducing unnecessary side effects [12]. At the same time, by combining artificial intelligence with multi-omics data to dynamically monitor patients' disease progression, doctors can be prompted to adjust patients' treatment plans in a timely manner, ensuring the timeliness, continuity, and personalization of treatment plans, and making treatment as close as possible to the requirements of true "precision medicine".

4.2 Unmanned Hospitals: The Future Medical Model Driven by Artificial Intelligence

With the continuous development of artificial intelligence technology, the new medical model of "unmanned hospitals" is gradually demonstrating great potential in the prevention and treatment of cancer at the grassroots level. Its core lies in the use of artificial intelligence systems and robots to take on the roles of doctors and nurses, thereby achieving the automation and standardization of the diagnosis and treatment process.

In the "early screening, early diagnosis, and early treatment" aspects of cancer prevention and control, unmanned hospitals can rely on artificial intelligence imaging recognition systems to quickly complete the screening and preliminary diagnosis

of suspected lesions, improving the screening efficiency and accuracy of grass-roots medical units. Even in the absence of professional radiologists, with the AI-assisted film reading system, preliminary judgments can be made on common lesions such as pulmonary nodules and breast masses, providing a basis for subsequent diagnosis and treatment.

In addition to diagnosis, unmanned hospitals can also combine robotics and the Internet of Things technology to achieve automated management in patient registration, sample collection, data upload, drug delivery and other aspects. This not only reduces human errors but also saves a large amount of human resources, making the medical process more standardized and efficient. At the same time, relying on cloud platforms, unmanned hospitals can break down the information barriers in regional healthcare and promote the integrated construction of cancer prevention and control centered around artificial intelligence. This, in turn, can address long-standing structural problems such as the shortage of medical resources and weak diagnostic and treatment capabilities at the grassroots level.

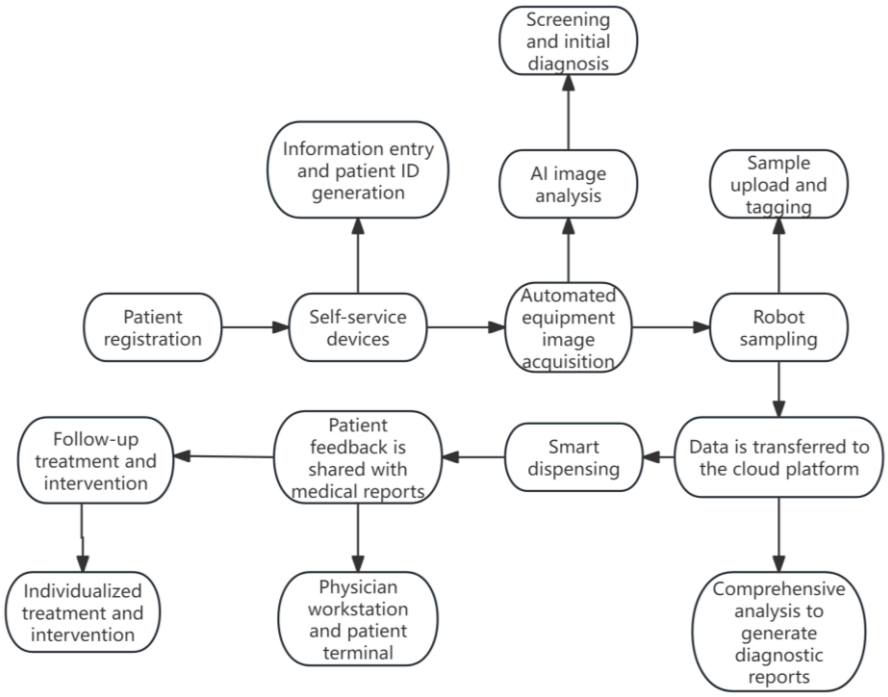

Figure 2: Workflow Diagram of Unmanned Hospitals

5. Conclusion

Artificial intelligence can bring a great deal of convenience to cancer prevention and treatment. However, as it is an emerging field in medicine, a complete medical data processing system has not yet been established at present, and it also faces some problems such as system failure, algorithm errors, and privacy leakage. Therefore, while enjoying the convenience brought by artificial intelligence, we also need to have a calm and objective understanding of it and prudently evaluate the clinical application boundaries of artificial intelligence.

In addition, related innovative products and medical models based on artificial intelligence are showing an explosive growth trend. To ensure that technological achievements truly serve the grass-roots population, it is necessary to conduct scientific and effective evaluations, select artificial intelligence products and medical models with clinical practical value, reliable safety performance, and suitability for grass-roots promotion, so as to achieve a high-quality development paradigm featuring innovation-driven, quality improvement and efficiency enhancement, and balanced and inclusive development, providing strong support for comprehensively promoting the “Healthy China 2030” strategy.

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Conflicts of Interest

The authors declare that there is no conflict of interest.

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