

Applications and Challenges of Large Language Models in Primary Healthcare: Postprint

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Abstract

Primary healthcare systems are pivotal to achieving health equity. China is confronted with severe challenges of medical resource imbalance, primary care physician shortages, and chronic disease prevention and control. Artificial intelligence large language models have demonstrated formidable advantages within healthcare systems. Building upon this foundation, this article thoroughly examines the applications of large models in primary healthcare systems and their attendant challenges, proposing to deepen large model deployment to assist primary care physicians in diagnosing and treating common diseases, promote intelligent health education and chronic disease management, underpin primary health services in remote, border, and impoverished areas, catalyze leapfrog development in general practice medicine, and advance the industrialization of large models in general practice diagnosis and treatment as well as primary health services, thereby providing crucial support for the Healthy China initiative.

Full Text

The Application of Large Language Models in Primary Healthcare Services and the Challenges

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Abstract

The primary healthcare system is crucial for achieving health equity. China faces severe challenges including imbalanced medical resources, shortages of primary healthcare providers, and the prevention and management of chronic diseases. Artificial intelligence large language models (LLMs) have demonstrated powerful advantages in healthcare systems. This article thoroughly explores the applications of LLMs in primary healthcare systems and their associated challenges. We propose deepening LLM applications to assist primary care physicians in diagnosing and treating common diseases, promoting intelligent health education and chronic disease management, supporting primary health services in underdeveloped and remote areas, stimulating leapfrog development in general practice, and advancing the industrialization of LLMs in general diagnosis and treatment as well as primary health services, thereby providing important support for Healthy China construction.

Keywords: Large Language Model; General Medicine; Primary Healthcare Services; Health Equity; Health Education; Chronic Disease Management

1. Introduction

Facing severe challenges of uneven medical resource distribution, shortages of primary care physicians, and chronic disease prevention and management, artificial intelligence technology—particularly large language models (LLMs)—offers innovative solutions for China’s primary healthcare services. With support from national strategies and the establishment of biological data systems, China is making rapid progress in developing and implementing medical AI technologies [1]. On June 6, 2024, the General Office of the State Council emphasized in its “Key Tasks for Deepening Medical and Health System Reform in 2024” [2] the need to strengthen primary healthcare service capacity, specifically highlighting improvements to infrastructure conditions in primary healthcare institutions and the promotion of smart medical assistance information systems. This indicates that intelligent tools like LLMs hold transformative significance for the modernization of China’s current primary healthcare services.

LLMs, or “large models,” are complex machine learning models with billions or even hundreds of billions of parameters capable of processing massive datasets and performing sophisticated tasks such as natural language processing, computer vision, and speech recognition. Training such models requires substantial

data to avoid overfitting and relies on high-performance computing equipment or cloud computing resources.

Since the release of ChatGPT (Chat Generative Pre-trained Transformer) in November 2022, LLM technology has attracted widespread attention in the healthcare field. Generalist Medical Artificial Intelligence (GMAI) has rapidly developed, demonstrating enormous potential and transformative impact. LLMs have achieved breakthroughs through scaled expansion, with models like GPT-3 and Med-PaLM-2 performing excellently on the United States Medical Licensing Examination (USMLE), where Med-PaLM-2 achieved 86.5% accuracy [3]. Microsoft's novel LLaVA-Med model, trained on large-scale biomedical image and text datasets, can process multimodal medical information, analyze medical images such as CT and X-rays, infer patients' underlying pathological conditions, and generate relevant Q&A content [4]. Researchers have evaluated LLMs' potential in healthcare applications, including improving medical consultation system efficiency, automatically generating multimodal medical reports, and applications in medical question-answering (QA) and dialogue systems [5]. By leveraging technologies such as Generative Adversarial Networks (GANs), Variational Autoencoders (VAEs), Diffusion Models (DMs), and LLMs, researchers can integrate various types of medical data (e.g., images, text, audio, time series). Regarding LLM security, generative large models face multiple threats including model theft, data theft, adversarial attacks, backdoor attacks, Prompt attacks, and data poisoning [6].

Generalist medical AI large models possess strong capabilities in text information processing and multimodal information fusion. Compared with previous AI models limited to narrow healthcare problems, GMAI offers significant advantages [5]: (1) **Complex data processing:** Healthcare data is complex, comprising images, text, numerical values, and various other types involving diverse medical terminology and complex condition descriptions. (2) **Generalization ability:** Unlike models trained for specific tasks, GMAI as a general-purpose model can theoretically adapt to various medical tasks such as disease detection, prognosis assessment, and patient risk prediction. (3) **High precision:** GMAI can achieve highly accurate results in solving complex medical problems like image recognition, genetic sequence analysis, and disease prediction. For example, when processing medical images such as MRI and CT scans, GMAI demonstrates exceptional image recognition capabilities. (4) **Real-time capability:** GMAI can perform real-time analysis and prediction on continuously generated new data, which is particularly important for clinical decision support systems. (5) **Personalization:** Large models can learn from vast amounts of patient data and provide personalized medical recommendations for each patient, enabling healthcare services to better address individual patient needs.

2. Current Status and Challenges of Primary Healthcare Services in China

As China's most widely distributed and populous health institutions, primary healthcare facilities undertake numerous critical missions including basic public health services, essential medical care, and normalized epidemic prevention and control, handling over half of the nation's total outpatient visits. They are the executors of the tiered diagnosis and treatment system and the "gatekeepers" of public health. However, in terms of departmental structure, primary healthcare institutions often leave patients with impressions of weak specialist diagnostic capabilities and difficulty in accurately determining disease types, particularly for vulnerable groups such as the elderly and children. Improving technical capacity in primary healthcare services is essential to enable people to access care conveniently and safely at the grassroots level [7].

Primary care is crucial for managing comorbidities and reducing health inequities. China currently faces issues including insufficient numbers of general practitioners, incomplete equipment in primary healthcare institutions [8], low outpatient volumes, and repeat visits. Low outpatient volume is a widespread problem in implementing tiered diagnosis and treatment systems across the country, which not only hinders the development of primary healthcare institutions and specialists from tertiary hospitals but also creates a Matthew effect that erodes patient trust [8]. Community hospitals also face shortages of medical staff, low education levels, limited clinical experience, suboptimal technical capabilities and service capacity, and untimely knowledge updates for general practitioners [9]. Currently, China has a severe shortage of qualified general practitioners who cannot meet public health service demands at the primary level. Primary healthcare institutions also face funding management issues in chronic disease management, including insufficient funds and inadequate allocation of special funds, which constitute major obstacles to deepening chronic disease management.

Chronic disease prevalence in China continues to rise annually, with prevention and control situations becoming increasingly severe [10]. Hypertension, diabetes, malignant tumors, and other chronic diseases have become major contributors to increased mortality, imposing enormous burdens on public health and social development while creating tremendous pressure for primary healthcare workers. Primary-level chronic disease management is crucial for reducing patient healthcare burdens [11], with statistics showing that 80%-90% of patient health problems can be resolved with assistance from community health service workers [12], while 80% of coronary heart disease, 90% of type 2 diabetes, and one-third of cancers can be prevented through measures like tobacco control, alcohol limitation, healthy diets, and maintaining normal weight [10]. From January to November 2023, national total outpatient visits reached 6.41 billion, of which primary healthcare institutions accounted for 2.24 billion visits (34.9% of the total) [13]. This indicates that tiered diagnosis and treatment has not yet achieved significant overall effectiveness, and high-quality development of

general practice still has a long way to go [14]. Increasing patient demands, chronic diseases, and resource constraints place pressure on the healthcare system. Meanwhile, digital health technology usage is increasing, and data across all healthcare settings is expanding. If properly utilized, primary healthcare workers can focus on disease causes and track the effectiveness of preventive measures and interventions.

3. Applications and Development Prospects of AI LLMs in Primary Healthcare Services

3.1 Assisting Diagnosis and Treatment of Common Diseases to Improve General Practitioners' Capacity and Work Efficiency General practice, as an interdisciplinary field in healthcare, requires its medical service models and content to continuously adapt to and meet the growing healthcare service demands of the people [15], necessitating continuous accumulation of experience and promotion of appropriate general practice technologies [14-15]. LLMs can help primary care general practitioners save non-clinical working time by automating routine and repetitive medical tasks, from medical data entry to efficient searching and summarization of medical information, generating comprehensive summaries covering patient history, potential diagnoses, and available treatment options [16-17]. They can also simulate clinical scenarios to provide practical training and skills for medical staff, enhancing clinical diagnosis and treatment capabilities [18-19]. Several domestic companies have developed medical AI systems using LLMs: Yidu Tech's AI platform aims to help Chinese hospitals operate more effectively in medical research, healthcare management, pharmaceutical research, and clinical decision support [20]; Baidu's PaddlePaddle AI platform is used for medical applications from diagnosis to prediction [21]; Alibaba's ET Medical Brain AI platform can integrate hospital logistics and diagnostic assistance to provide better treatment outcomes by incorporating data from electronic health records and patient images [21]; Tencent Lab's AI products integrate electronic medical records and disease risk prediction while automatically analyzing medical images such as CT and PET scans to assist doctors in diagnosis [21].

Communities and rural areas are the "last mile" of healthcare services [22]. By introducing auxiliary diagnostic systems that meet the needs of primary care physicians, we can break down barriers, eliminate gaps, comprehensively strengthen the specialist skills of community and rural general practitioners, and help them improve their capabilities across the entire spectrum of consultation, diagnosis, and medication. This addresses challenges of staff shortages and insufficient knowledge updates, improves diagnostic accuracy, reduces misdiagnosis and missed diagnosis, achieves "AI + Expert" dual review, enhances diagnostic efficiency and accuracy, fulfills the goal of "letting AI assist in seeing patients while doctors focus on caring for people" [23], optimizes treatment plans, enhances treatment capabilities for chronic diseases, pediatrics, oncology, and other conditions, improves treatment outcomes, and informs primary care

physicians when to refer patients and where to refer them, providing the most efficient and scientific decision-making.

3.2 Intelligent Health Education to Provide Scientific Knowledge and Psychological Counseling Services The development of large models and information technology has enabled chatbots and mobile applications to support large-scale public health monitoring and interventions. Advances in artificial intelligence and natural language processing (NLP) have opened promising pathways for supporting population-level health education. Chatbots are particularly considered effective tools for expanding capacity because they can provide health information and emotional support [24]. Large models can accommodate vast medical knowledge and, by collecting user data (such as age, gender, health status), explain in understandable ways to provide personalized health recommendations. In disease prevention, large models can perceive and assess users' disease risk through risk prediction, issue early warnings, and guide timely preventive measures. At the mental health level, large models engage in free-form dialogue on open topics with empathy as the primary goal. Such systems benefit public health interventions by providing empathetic interactions for populations with different health experiences and reaching broader underserved groups. Simultaneously, large models can provide psychological counseling services to help users manage stress and improve quality of life. Artificial intelligence is not simply about automating tasks but developing technologies that can enhance patient care in healthcare settings. Patients can describe their needs in everyday language, allowing generalist medical AI models to adapt to new tasks without retraining multimodal large models or training them to accept different types of unstructured data to generate responses [16].

3.3 Digital and Intelligent Health Management to Provide Full-Cycle Precision Personalized Chronic Disease Management In terms of technological innovation, medical large models have empowered chronic disease prevention and control to enter a new stage. In scenario applications, continuous progress has been made in chronic disease “prevention-diagnosis-treatment,” featuring more proactive prevention models, more precise diagnostic methods, and more diverse treatment approaches. Future development trends for chronic disease prevention and control are proposed to be “precision,” “individualization,” “digital-intelligent integration,” and “integration” [10]. LLMs utilize patients' medical records and current conditions to provide personalized care recommendations and help tailor care plans [25]. LLMs assist general practitioners in managing and accurately administering medications with timely reminders for doctors and patients. Large models enable remote monitoring of patient health, analyzing physiological parameters, device data, and health records to help doctors manage diseases, reduce hospitalizations and emergency visits, and improve remote care experiences through telemedicine advice and nursing guidance. Google's team developed a Personal Health Large Language Model (PH-LLM) [26] and Personal Health Insights Assistant (PHIA) [27] based

on wearable health monitoring device data, while the mental health application Woebot Health seamlessly integrates LLMs into existing AI products to fully leverage LLMs' potential in precision behavioral health management [28]. Digital Health Technologies (DHTs) utilize AI to monitor patient seizures, diabetes, and cardiovascular disease clinical management, reducing burdens on patients and primary healthcare staff while decreasing structural inequalities in care access [29]. Meanwhile, elderly individuals need to overcome loneliness and emotional burdens. Large models can monitor residents' health, call to inquire about health needs when detecting anomalies—such as asking “Why didn't you sleep well last night? Did you encounter any problems?” or “Have you tried the additional measures I suggested last time? How do you feel?” The realization of these large model capabilities is crucial for achieving people-centered primary healthcare services [30].

3.4 Intelligent Management of Healthcare Services to Promote Modernization of Primary Healthcare Service Systems Large models must also leverage the core competitiveness of combining prevention and treatment in general practice [15]. Hospital intelligent follow-up systems, based on AI voice and natural language understanding technologies, enable batch outbound calls, human-computer interaction, and automatic statistics to assist hospitals in comprehensive follow-up work including satisfaction surveys, health education, department follow-ups, research follow-ups, and critical value alerts, reducing follow-up costs and improving medical staff efficiency. Through coordinating resources across regions, equally high-quality services can be achieved, with remote interaction and high-level medical resources providing quality control for large model terminals and timely feedback. Additionally, through patient-side health instruction systems, daily health guidance is provided, medication reactions are monitored, and potential risks are flagged.

For China's other essential public health service projects, large models also have corresponding application scenarios, such as assessing risk levels for each pregnant woman. Applying maternal risk warning models can significantly improve pregnancy management efficiency and quality, including monitoring maternal health, predicting risks of preterm birth and miscarriage, gestational diabetes, pregnancy anemia, and postpartum depression, as well as neonatal pain assessment and sepsis prediction [31], substantially reducing maternal and neonatal mortality rates. For intelligent health management of children aged 0-6, large models can efficiently and accurately complete planned immunization work. For healthy residents, large model intervention will help timely identify needs for family doctor contract services and implement resident health risk management. By saving labor costs, there is potential to further increase universal basic public health service subsidies, upgrade service packages, and enhance service quality.

4. Ethical and Responsibility Issues in Large Model Applications

With the aid of large model tools, we anticipate that primary healthcare decision-making processes will become more scientific and systematic, solving more problems beyond common diseases, reducing burdens on large hospitals, and ensuring patients receive the highest standard of medical care at all levels [32]. China's tiered diagnosis and treatment system construction is based on "health needs" with the goal of achieving "collaborative governance" [33]. The current focus of tiered diagnosis and treatment work is to guide the public to change their healthcare concepts and habits, gain comprehensive understanding of primary healthcare institutions' functions, and avoid blindly flocking to large hospitals [8]. The emergence and application prospects of large models will greatly promote implementation of tiered diagnosis and treatment policies by improving primary healthcare service quality, coverage, timeliness, and cost-effectiveness, thereby establishing patient trust and reliance on primary healthcare institutions. Additionally, we must leverage the role of medical communities, using the strength of higher-level hospitals to assist in precise use and quality assurance of large models in primary healthcare service institutions, rapidly enhancing primary care general practitioners' professional capabilities to enable them to confidently handle common and chronic diseases and develop correct abilities to analyze test reports—key to attracting patients and fulfilling tiered diagnosis and treatment [8]. Meanwhile, when higher-level hospitals manage primary healthcare institutions' medications, large models will real-time predict supply and demand of various drugs, making inter-pharmacy coordination and city-wide drug distribution more efficient and accurate. Coordinated allocation of medical resources, improved supply-demand matching efficiency, standardized patient visit order, and promotion of equitable access to disease medical services are of great significance for advancing national governance system and governance capability modernization.

The main ethical principles for applying AI in health and other fields aim to guide developers, users, and regulators in improving and supervising such technologies. Human dignity and intrinsic human value are the core values underlying all other ethical principles. Ethical principles are important for all stakeholders including clinicians, system developers, health system managers and policymakers, and local and national governments. Governments and public sector institutions should be encouraged and assisted to keep pace with rapid AI technology development through legislation and regulation, and medical professionals should be enabled to appropriately use AI technology. Ethical principles should also be embedded in AI professional and technical standards [38].

From a legal perspective, AI lacks human legal status. Medical personnel and hospitals using LLMs require training and thus bear ultimate responsibility for their use [39]; however, determining legal liability in cases of patient harm is complex, with responsibility among patients, hospitals, doctors, and LLMs being very ambiguous, requiring clear regulations and legal limitations to appropriately allocate responsibility and protect users [40-41]. Some LLMs pro-

vide misleading or potentially dangerous advice, highlighting the need for cautious adoption in clinical settings; nevertheless, LLMs are expected to transform healthcare [42].

If healthcare providers are penalized for relying on AI technology conclusions that prove wrong, they may only use the technology to confirm their own judgments. While this might exempt them from liability, it would hinder exploitation of AI's maximum potential. LLMs should be used to augment rather than merely validate human judgment [43]. If doctors are not penalized for relying on LLM technology, even when its suggestions contradict their own clinical judgments, they may be encouraged to more widely use these technologies to improve patient care, or at least consider using LLMs to challenge their own assumptions and conclusions [43]. Therefore, with clear responsibility allocation when LLMs are fully developed, their value can be comprehensively realized. Regarding privacy and regulatory issues, LLMs still pose inherent risks of compromising patient privacy, and AI regulatory systems remain imperfect, with stricter regulatory mechanisms still needing development [40].

5. Challenges and Prospects for Large Models in Primary Healthcare Services

With rapid technological development and iteration, large models are being applied more deeply in primary healthcare service fields, providing possibilities for solving current key and difficult problems. However, large models still face the following challenges in primary healthcare service applications:

First, **lack of interdisciplinary talent**. The development of large models in primary healthcare systems requires more biomedical engineering talent and medical-engineering interdisciplinary personnel to participate in research and development to fully tap the application potential of large models and effectively integrate them into medical work to meet the needs of primary healthcare systems.

Second, **model accuracy issues**. Large models rely on selected datasets for training and analysis, with dataset establishment determined by researchers. Ensuring high-quality training data, appropriate model design and selection, continuous model optimization and validation, and professional clinical understanding are required, with data representativeness, quality, and generalization ability needing verification.

Third, large models can help patients maximize treatment benefits in medical decision-making but may easily overlook patients' needs for humanistic care [44], and may demonstrate inconsistency with human values in model creation and use [45]. Large model technology development and trial use must not cause primary healthcare staff to relax their responsibilities, and medical personnel must not completely rely on large model technology while ignoring its limitations. We must grasp the advantages and limitations of AI output results and make supporting investments to educate doctors on how to properly handle data from

large model devices [29].

Finally, **residents have varying acceptance levels of smart devices**. Patient acceptance of new service models is influenced by factors such as age, gender, region, and knowledge of chronic diseases [46]. Human-computer interaction models must more conveniently serve elderly patients. Large model intelligent terminals must accurately understand user instructions and execute them smoothly, including addressing potential dialects and unclear articulation in elderly patients to avoid ambiguity that could lead to incorrect diagnoses and recommendations.

6. Conclusion

AI and LLM technology have promising application prospects in China's primary healthcare services. We must seize current opportunities to launch "Large Model + Healthy China" construction, deepen medical large model research and application, promote digital-intelligent chronic disease prevention and control, stimulate leapfrog development in general practice, advance industrialization of large models in general diagnosis and treatment and primary health services, bring historic transformation to the "last mile" of healthcare services and essential public health services, compensate for health workforce shortages and inequitable distribution, provide leapfrog means for achieving health equity, and help realize the Healthy China blueprint.

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