

RESEARCH ARTICLE

Combining Artificial Intelligence with Traditional Chinese Medicine for Intelligent Health Management

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Abstract

The growth of artificial intelligence (AI) is being referred to as the beginning of "the fourth industrial revolution". With the rapid development of hardware, algorithms, and applications, AI not only provides a new concept and relevant solutions to solve the problem of complexity science but also provides a new concept and method to promote the development of traditional Chinese medicine (TCM). In this study, based on the research and development of AI technology applications in biomedical and clinical diagnosis and treatment, we introduce AI technologies in current TCM research. This can have applications in intelligent clinical information acquisition, intelligent clinical decision, and efficacy evaluation of TCM; intelligent classification management, intelligent prescription, and drug research in Chinese herbal medicine; and health management. Furthermore, we discussed the development prospect of intelligent TCM.

Key Words: *Traditional chinese medicine (TCM); Artificial intelligence; Intelligent TCM; Health management*

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1. Introduction

From the establishment of personalized medical system of "treatment based on syndrome differentiation" in Treatise on Exogenous Febrile Disease (Shanghan Lun) in the 2nd century AD to the proposal of precise medicine of traditional Chinese medicine (TCM) in recent years [1], individualized medical treatment in TCM has made great achievements in health maintenance, clinical practice, and research development; however, it still encounters many difficulties. With the development of modern science and technology, the main challenge lies in how to achieve efficient intelligent prediction, prevention, diagnosis, treatment, and rehabilitation. Maintaining or intervening with the dynamically changing human body, which is an open and complex giant system, for maintaining or restoring its normal state, while at the same time continuously inherits and improves itself, is difficult.

Artificial intelligence (AI), also known as machine intelligence, refers to a system that correctly interprets external data and learns from it to further flexibly achieve specific goals and tasks [2]. For example, AlphaGo learned several Go manuals and achieved major milestones in the Go world. Watson robot entered the medical field and provided precise oncology support for clinical use [3]. Deep neural networks and symbolic AI were used for reverse synthesis analysis in the field of chemistry [4]. The latest AlphaFold by Google accurately predicts the three-dimensional structure of proteins according to the amino acid sequence. In addition, a new imaging method based on AI technology reduces the error of 3D positioning of glioma up to 10 microns [5]. The revolution brought by AI is developing rapidly and has penetrated the field of medicine and pharmacy, becoming a hot topic in the field of medicine. AI has ignited new hope for the development of personalized and accurate medical treatment in TCM.

China's three Internet giants are also actively laying out the AI medical blueprint. Baidu introduced a medical AI plan with big data resources and processing ability as the core -- "Baidu medical brain"; Ali Health launched the "Doctor You" medical AI system, which includes clinical medical scientific research and diagnosis platform, medical auxiliary testing engine, medical ability training. Tencent also released an open platform for AI medical auxiliary diagnosis and treatment, and a new product named "Tencent Miying" to realize effective assistance for diagnosis and early screening of major diseases. Meanwhile, the application of AI technology in the field of TCM has also started.

Intelligent TCM deeply integrating AI technology with TCM and then setting up a series of methods suitable for TCM research and application of AI technology to promote the development of TCM. The development of AI technology has an increasing impact on TCM [6, 7]. Thus, an intelligent TCM system for disease prediction, prevention, health care, diagnosis, treatment, and rehabilitation can be developed.

This paper summarizes the research and application status, and development prospect of AI technology in the field of TCM from the viewpoint of intelligent collection of clinical information in TCM, intelligent clinical decision-making, as well as prescription treatment and health management in TCM, so as to provide reference for researchers to engage in this new interdisciplinary field.

2. Collection of Clinical Information in TCM

One of the core elements of AI is data. However, TCM clinical diagnosis relies on personal subjective experience through four diagnostic methods: inspection, listening and smelling, inquiry, and palpation and pulse taking. Therefore, objectively, digital and standardized collection and labeling of the information using the four diagnoses is the first step of intellectualization in TCM. Currently, the combination of intelligent diagnostic equipment and TCM has encouraged the standardization of data acquisition and research on the information of the four diagnostic methods in TCM.

2.1. Inspection

Inspection means observing systemic or local signs and effluents governing the exterior to understand the internal condition and changes of the human body; among these, face and tongue inspections are the most unique. Currently, tongue images captured by TDA-1 tongue imaging equipment in TIFF format can be recognized using ICC contour correction; the average of different tongue colors can be compared and the effect of tongue color classification can be evaluated using a machine learning method. The SMOTE algorithm can be used to solve the imbalance of different color samples to improve the classification accuracy [8]. A new feature set based on color space can be extracted from the tongue image of clinical patients. The syndrome types can be determined by observing the tongue color and tongue coating. Then, an automatic classification system can be constructed. The relationship between tongue features and syndromes can be established using machine learning technology. A total of 263 patients with gastritis were distinguished for the cold/heat syndrome based on this method [9]. Inspection robot developed by the Chinese Academy of Sciences uses machine vision technology to measure the color and shape singularity of the facial reflection area. It can screen and evaluate 10 major human systems and more than 70 health indicators in 15 s through the analysis of hundreds of photographs captured by a camera and data collected by the biosensor based on the TCM face inspection, and also through western medicine physical examination and AI algorithm.

2.2 Listening and Smelling

Listening and smelling in TCM refer to listening to patient's speech, coughing, and wheezing, and smelling patient's breath and body odor. The commonly used methods of voice acoustic detection in a clinic include detection of voice and voice function using a sound spectrograph, spectrum analyzer, and an instrument with functions to obtain sonogram, spectrogram, and electroglottograph. Voice signals of patients with liver depression and spleen deficiency, heart-spleen deficiency, and heart-kidney non-intersection were collected by sound diagnosis technology; their characteristic parameters were analyzed and distinguished [10]. By integrating AI technology and the essence of TCM theory, an intelligent listening diagnosis system launched by Pingan health cloud company can quickly collect sound information and identify the TCM constitution of the voice subject. A team at Rockefeller University used AI to predict molecular odors and large olfactory psychophysical datasets to develop machine learning algorithms for predicting molecular sensory properties based on chemical information characteristics [11]. Currently, compounds in air or breathing samples can be detected by gas chromatography mass

spectrometry (GC-MS). The analysis results are used to extract features from deep neural networks. These technologies have great potential for the application of intelligent diagnosis through smells in TCM.

2.3. Inquiry

The etiology, course of onset, past medical history, conscious symptoms, and emotional, dietary, living habits and other conditions related to a disease should be collected through inquiry. With the development of speech recognition and natural language processing (NLP) technologies to extract and create algorithms for mining medical document data from unstructured text [12], speech recognition can work in parallel with NLP to achieve human-computer interaction, which can be used in many medical scenarios such as inquiry dialogue, symptom collection, diagnosis and treatment interpretation, and follow-up after diagnosis. On December 15, 2018, at the first World Federation of Chinese Medicine Big Data Development Forum, a doctor-patient AI dialogue system named "Dr. Bang" was officially released, which was also the first doctor-patient AI dialogue system in the field of TCM. Based on speech recognition, NLP, deep learning, and TCM domain knowledge atlas, the system integrates voice dialogue platform and symptom reasoning engine, and automatically collects and generates structured electronic medical records for inquiry.

2.4. Palpation and Pulse Taking

Palpation and pulse taking are examinations of pulse changes, body lumps, skin temperature, and pain areas. Since the 1950s, there have been many objective studies on pulse detection, recording, and qualitative and quantitative analysis, which have laid the foundation for intelligent palpation and pulse diagnosis. It has been reported that the diagnostic accuracy of TCM pulse signs in patients with fatty liver disease and liver cirrhosis is more than 93% on the basis of supervised learning least squares regression (LS) and least absolute shrinkage and selection operator (LASSO) [13]. There is a study on the consistency of machine learning algorithms in assessing the combination of physical characteristics of pulse signals and predicting hypertension with sphygmomanometers. It has been found that the maximum pulse amplitude of left and right guan pulse is a good index of hypertension [14]. In addition, the application of deep neural networks in the diagnosis and classification of dynamic electrocardiogram arrhythmias has been reported [15]. By combining non-invasive testing equipment and AI technology, feedback data can be obtained and analyzed by imitating human touch and pressing. It is also a method to fully utilize the advantages of non-invasive testing in TCM palpation and pulse diagnosis to distinguish the ups and downs of the viscera function and deficiency of qi, blood, and essence.

Intelligent application of the four diagnostic methods can provide effective basis for the observation of disease development and evaluation of clinical efficacy [16]. Moreover, objective data collection and analysis from the whole human body are also useful. For example, an infrared thermal imaging system collects information on the energy changes of the human body [17] and brain deep image reconstruction system collects and transforms signals of brain activity [18]; this suggest the feasibility of using AI technology to explore the holistic view of TCM from the perspective of material, energy, and information.

2.5. Detection of Objective Indicators

Besides the four methods of diagnosis, clinical diagnosis in modern Chinese medicine also needs to use western medicine detection methods for combining macroscopic and microscopic syndrome differentiation to reduce misdiagnosis and missed diagnosis. AI has unique advantages over human eyes in the field of imaging and pathology for image feature extraction and analysis. In addition to forecasting and diagnosing illnesses by directly extracting the features of medical images [19], AI can also model the structure of the human body in three dimensions, realize localization, recognize micro diagnostic and therapeutic equipment such as endoscopic robots in the human body, extract and analyze the features of medical images by unsupervised learning, reduce the dependence on data labeling, and facilitate medical image scoring [20]. Furthermore, constructing an intelligent diagnosis model based on the combination of multi-modal data acquisition analysis and structured knowledge reasoning of TCM by utilizing large amounts of systematic biology and medical data such as genomics, transcriptome, proteomics, metabonomics, metagenomics, and imageology will also be a part of future research.

3. Application of AI for Treatment using TCM

The study of AI in TCM began in the 1970s. At that time, a series of expert systems for TCM were designed by imitating the clinical experience of doctors or digging classical works on TCM. With the rapid development of Internet and computer technology, we can quickly obtain large amounts of medical data. Meanwhile, depending on the continuous optimization of intelligent algorithms, the intelligent treatment model of TCM is becoming more accurate.

3.1. Intelligent Clinical Decision-making for TCM

In the critical illness model project of Mayo clinic, the theory of Yin-Yang and five elements of TCM was introduced to be used with the intensive data of western medicine to form an innovative mathematical model; this can provide real-time decision support to assist doctors in predicting and judging illness. TCM syndrome differentiation was regarded as a black box, which can classify patients into different categories according to their symptoms. Computer-aided medical decision-making (CAMDM) is a method that uses a lot of electronic case data as experience and evidence support in the decision-making process. Traditional models are not suitable for the analysis of TCM cases because of the complexity of abstract concepts. Therefore, a deep belief network (DBN) model combined with conventional shallow model was proposed to simulate information analysis and decision-making process in medical practice, which improves the performance of the CAMDM system in clinical application of TCM [21]. Through reliable multi-label learning, AI maintains stability in the confidence range of 80% to 100% for the identification of four syndromes of chronic fatigue in TCM, namely "spleen deficiency," "heart deficiency," "liver depression," and "qi deficiency," indicating its robustness to threshold determination [22]. In the process of clinical practice of TCM, the relationship between symptoms and syndromes of patients is often complex and non-linear due to which surface structure algorithm cannot be solely used. TCM syndrome diagnosis and/or treatment could be by a AI-based TCM assistive diagnostic system [23]. The diagnostic model of TCM chronic gastritis syndromes based on in-depth learning and multi-label

learning can improve the accuracy of syndrome identification and provide a reference for guiding clinical decision-making [24].

3.2. Management, Prescription and Research on Chinese Herbal Medicine (CHM)

The quality of CHM is the basis of clinical efficacy of TCM; its standardization is one of the most important aspects of the modernization of TCM. However, the objective evaluation and effective control of the quality of CHM is still a difficult problem. With the help of AI, the quantitative analysis of quality markers of CHM can be realized, and the overall quality control and traceability system can be established; this can provide a quick and simple detection method for quality evaluation of CHM [25]. Inspired by the progress of in-depth learning for computer vision, researchers realized that deep learning methods can provide powerful medical image support. Using convolutional neural networks for image recognition and retrieval in CHM, 71% average recognition accuracy and 53% average retrieval accuracy was achieved in 95 medical categories [26]. At present, research on intelligent prescription of CHM is mainly based on the text description of symptoms, which can be used to automatically generate prescriptions. However, it still needs to be connected to the prescription verification system, the prescription needs to be checked by doctors, and the medication plan needs to be confirmed according to the patient's specific condition [27]. The progress of AI in directional drug design and molecular therapy also provides new ideas for the research and development of CHM [28]. Researchers found that compared with the traditional machine learning model, a deep learning method has higher sensitivity, specificity, precision, and accuracy in predicting the effects of clearing heat, promoting blood circulation, and removing blood stasis [29]. Four different machine learning methods are used to study the quantitative structure-property relationship of natural product datasets of TCM; the consensus model will accelerate the understanding of the mechanism of absorption, distribution, metabolism, and elimination of natural products [30].

3.3. Therapeutic Evaluation and Mechanism Study

There is no unified and objective criterion for the evaluation of the efficacy of TCM like western medicine. To gain greater recognition and promotion of TCM in the international community, it is necessary to explore an efficacy evaluation system that conforms to the characteristics of TCM. Many attempts have been made to investigate the efficacy and mechanism of TCM with modern technology and methods; AI key technologies provide new means for evaluation and analysis. Machine learning algorithms have been used to construct a classifier to predict active molecules targeting 25 key targets of Alzheimer's disease and further study CHM for treating the disease [31]. A supervised classifier is trained by using the physicochemical properties of compounds obtained from high-throughput screening; their robustness is verified by various statistical parameters. Then, the best machine learning model is used to screen new compounds that inhibit the invasion of erythrocyte by *Plasmodium falciparum* from the database of TCM [32]. There is also a study on the use of machine learning to analyze molecular pathways for constructing a comprehensive multi-objective pharmacological mechanism to predict the workflow, which reveals the comprehensive anti-arrhythmic multi-protein target network of Wenxin Granule [33].

4. Health Management

Along with the trend of global aging population and the improvement in medical and health conditions, chronic non-communicable diseases have become the main cause of death. In the 21st century, the medical object has changed from acute infectious diseases to chronic diseases, whereas the mode of intervention has changed from disease control to lifestyle intervention; the purpose of medicine has metamorphosed from treating diseases into maintaining health. Future medicine will be a "health medicine" for all, required through the entire course of life.

4.1. Prediction, Prevention and Rehabilitation

High sensitivity enables AI to demonstrate its advantages over human resources in early disease identification, prediction and prevention [34]. One of the core functions of precision medical treatment is that people are expected to be told that they may suffer from certain diseases in the future for better prevention, which is consistent with the preventive concept of "Preventive Treatment of Diseases" in TCM. Individualized early detection and targeted prevention will greatly reduce the cost of health maintenance [35]. Currently, deep learning has attained expert status in diagnosis of skin cancer [36]. In addition to early identification and prevention of organic diseases, AI robots can also measure mental states and changes, and even have the ability to communicate with and teach autistic children. A study reported that online AI role-playing simulation and emotional response can detect early emotional disorders, including depression and suicidal tendencies, in Native American reserved adolescents and is more effective than human intervention [37]; thus, intelligent TCM can be useful for the prevention and treatment of emotional disorders. AI can also be used to judge the correctness of patients' rehabilitation exercises according to the instructions of robots during rehabilitation nursing, and to achieve better sustainable rehabilitation nursing services in remote living environments [38]. Similarly, in the field of rehabilitation nursing, by analyzing the operation and demand of traditional Chinese massage, researchers have established an efficient full coverage path planning algorithm model, built an experimental platform for the massage robot, and improved the intelligence level and effect of massage of the massage robot [39]. Moreover, the breathing signature can be a vitality score index using machine learning technologies in the exercises of Qigong [40]. It also indicated the AI-medicine algorithm could be applied in the TCM.

4.2. Dynamic Health Management

AI Chinese medicine robots can identify the physique of users, and issue disease tendency and daily maintenance guidance reports; they can then provide personalized TCM health care services for users. However, the systematic thinking about the dynamic management of TCM health not only focuses on the traditional interaction between users and instructors but also considers the larger cycle and organization. Some examples can be used as reference for the intellectualized construction of a TCM health management system, such as family health care for the elderly in 3D virtual environment based on wearable sensors and human activity simulation [41]; modeling complex social ecosystems in the real world to help community health managers clarify the complexity of the system and find effective interventions at a lower cost [42]; using electronic medical records as AI data and applying specific algorithms to identify people with a family history of genetic diseases or a high risk of chronic diseases. Simultaneously, dynamic health

management system cannot remain unchanged but must learn from the data for continuous process improvement. Therefore, the implementation of comprehensive electronic health records needs to be accelerated. Data needs to be collected in real time and be open source under the premise of protecting personal privacy [43]. With the deployment of intelligent hardware and the rapid development of personalized gene sequencing services, a large amount of data is obtained from wearable health sensors. With the profit from the unprecedented amount of data along with the progress of NLP and social cognitive algorithms, the application of AI combined with the concept of "Preventive Treatment of Diseases" in TCM will shape the future personalized and participatory dynamic management system.

5. Future Directions

There are still many variables for the implementation of intelligent TCM. A powerful AI system needs enough data for constant training. It requires a mechanism to unceasingly improve itself and perform self-learning; it should also have a powerful computing ability. Therefore, in-depth application of AI requires much more than technology, money, and data sources. The difficulties in sourcing of clinical data, and the standardization and scale of TCM remain to be solved. However, scientific research institutes and enterprises are promoting the development of TCM industry and combining it with AI. Therefore, there are expected to be future prospects of intelligent TCM.

Intelligent TCM will not completely replace a traditional Chinese physician for diagnosis and treatment but combine human biological intelligence with AI. By using a cognitive model to update the knowledge of an AI system, the cognitive level of Chinese medicine can be improved to build an intelligent Chinese medicine system with human-machine collaboration. The key technology of AI in the field of TCM mainly includes image recognition, voice interaction, phonetic transcription, NLP, data mining, and cognitive computing, as shown in Figure 1.

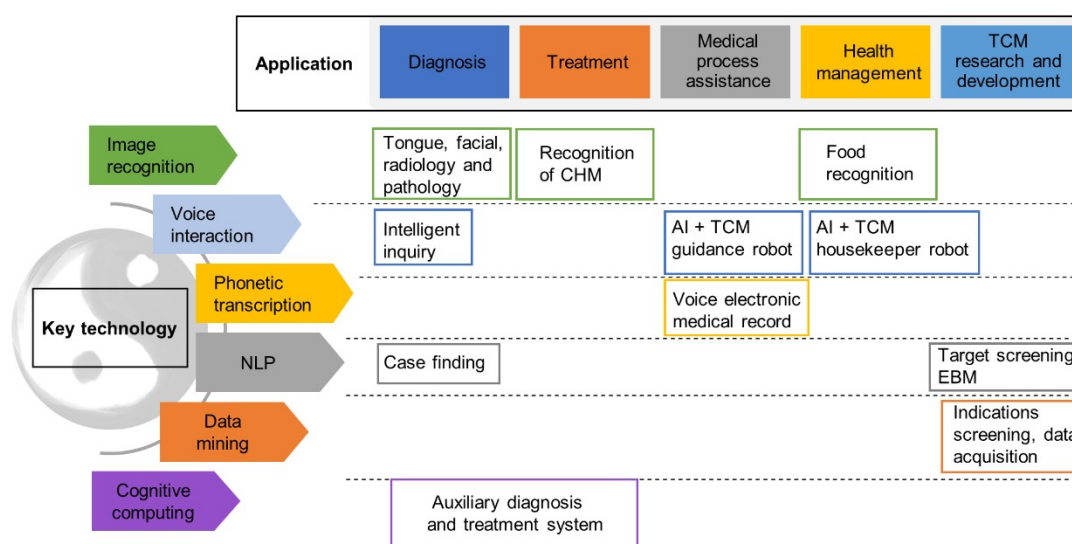


Figure 1: Key technology of AI in the field of TCM.

In the future, intelligent TCM may be used in daily life: smart devices that combine features and advantages of TCM may be seen everywhere; four diagnostic information may be collected and displayed in real time; and an intelligent TCM housekeeper may be able to provide daily diet and living suggestions based on syndrome differentiation data, make a former diagnosis judgment of a disease and upload it to the cloud, and also make an appointment with the appropriate doctor through an intelligent triage system. From the perspective of doctors, intelligent TCM can empower them. They could use the TCM viewpoint to propose new rules and understanding of diseases and develop instruments and equipment suitable for the diagnosis and treatment accordingly. The system could assist doctors to complete the final diagnosis and treatment of diseases, standardize control of TCM, and optimize the allocation of medical resources. In addition, intelligent TCM uses AI algorithm to analyze and learn the complex compatibility rules of TCM, which is different from the research and development of western medicine. The discovery and optimization of the multiple component compatibility formula of Chinese medicine will open a new direction for the research and development of new Chinese medicine. This new era of intelligent TCM will realize the leap from data to knowledge and from knowledge to intelligence, thus, establishing a cross-field medical knowledge center linking individuals and medical institutions and form an open and interconnected medical information sharing mechanism. And we will move towards a future where intelligent TCM could be more beneficial to human health.

Author Contributions

FC drafted the manuscript. FC and YL collected Data; SS, LM and YH conceived of the study, and participated in its design and coordination and helped to draft the manuscript. All authors read and approved the final manuscript.

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