Original Article

Current status and trends of artificial intelligence research on the four traditional Chinese medicine diagnostic methods: a scientometric study

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Background: With the development of technology and the renewal of traditional Chinese medicine (TCM) diagnostic equipment, artificial intelligence (AI) has been widely applied in TCM. Numerous articles employing this technology have been published. This study aimed to outline the knowledge and themes trends of the four TCM diagnostic methods to help researchers quickly master the hotspots and trends in this field. Four TCM diagnostic methods is a TCM diagnostic method through inspection, listening, smelling, inquiring and palpation, the purpose of which is to collect the patient's medical history, symptoms and signs. Then, it provides an analytical basis for later disease diagnosis and treatment plans.

Methods: Publications related to AI-based research on the four TCM diagnostic methods were selected from the Web of Science Core Collection, without any restriction on the year of publication. VOSviewer and Citespace were primarily used to create graphical bibliometric maps in this field.

Results: China was the most productive country in this field, and *Evidence-Based Complementary and Alternative Medicine* published the largest number of related papers, and the Shanghai University of Traditional Chinese Medicine is the dominant research organization. The Chengdu University of Traditional Chinese Medicine had the highest average number of citations. Jinhong Guo was the most influential author and *Artificial Intelligence in Medicine* was the most authoritative journal. Six clusters separated by keywords association showed the range of AI-based research on the four TCM diagnostic methods. The hotspots of AI-based research on the four TCM diagnostic methods included the classification and diagnosis of tongue images in patients with diabetes and machine learning for TCM symptom differentiation.

Conclusions: This study demonstrated that AI-based research on the four TCM diagnostic methods is currently in the initial stage of rapid development and has bright prospects. Cross-country and regional cooperation should be strengthened in the future. It is foreseeable that more related research outputs will rely on the interdisciplinarity of TCM and the development of neural networks models.

Keywords: Scientometric analysis; artificial intelligence (AI); four TCM diagnoses; VOSviewer; Citespace

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Introduction

The four traditional Chinese medicine (TCM) diagnoses are a non-intrusive approach for doctors to diagnose diseases and involve inspection, auscultation, inquiring, and palpation. These diagnostic methods have been widely used in China for the past 3,000 years (1). Tongue, pulse, and facial diagnoses are recognized diagnostic methods in TCM, which are based on the overall evaluation of the heart, liver, spleen, lungs, and kidneys inside the human body. With the occurrence of disease, the changes in the functions of blood vessels and organs will be reflected in the tongue, pulse, and face manifestations. Thus, the color, thickness, frequency, and smell of these areas can be used to understand the severity and cause of disease. With the rapid development of TCM research, the four TCM diagnoses have advanced accordingly with modern science and technology (2), including artificial intelligence (AI). AI was proposed by McCarthy *et al.* in the 50s of the 20th century (3). Since then, AI has been rapidly developed and widely used in different fields such as finance and medicine. In recent years, due to the development of big data in TCM, the field of image analysis of TCM has become a hot spot in artificial intelligence research. With predictive analytics on AI-based medical images, doctors can make better diagnosis and treatment decisions. Many meaningful tongue and pulse features for the diagnosis of various diseases have been discovered using large amounts of complicated clinical data via AI-based data mining methods. For instance, the multi-step approach (4), Genetic Algorithm_Extreme Gradient Boosting (GA_XGBT) model (5), random forest (6), and convolutional neural network (MIMT-CNN) (7) have been widely applied in diabetic tongue research, while AdaBoost (8), Support Vector Machine (SVM) (9), and logistic regression (10) have been applied in pulse research. The use of AI to understand the clinical data of diseases can help to objectively and efficiently improve the accuracy and precision of diagnosis (2).

Up to now, AI-directed four TCM diagnoses have achieved significant progress in several fields. However, there are still difficulties in the development of AI-directed four TCM diagnostic methods, including model interpretation, unstable and sufficient clinical data, external model validation, explaining the relationship between the machine learning model and ancient Chinese philosophy, the quantification of smelling, the standardization of tools for collecting data, and well-designed storage databases or cloud database creation. Scientometric study is a quantitative method of studying the impact of a society and comparing its impact at different national levels (11). It can objectively show the contribution of a research field and analyze the hot spots and trends in that research field. In this study, we applied scientometric approaches and visualization tools to integrate information.

This review summarizes the current status and trends of AI research to discover novel information about the four TCM diagnostic methods and develop and investigate this TCM approach and its challenges.

Highlight box

Key findings

- AI research on the four TCM diagnostic methods has been developed since 2007; China has the highest number of authors, articles, and institutions in this field, but its influence needs to be strengthened. Tongue diagnosis and classification based on deep neural networks will be a research hotspot in this field for a long time.

What is known and what is new?

- Analysis of large amounts of complicated clinical data using AI methods has been widely applied in the field of tongue and pulse research.
- Through bibliometric methods, we assessed and visualized the current status of AI-based research on the four TCM diagnostic methods according to the country, journal, organization, author, keywords, etc.

What is the implication, and what should change now?

- There is a need for more interdisciplinary, cross-country, and cross-institutional collaboration in AI research on the four TCM diagnostic methods.

Methods

Search strategy and selection criteria

The Science Citation Index Expanded (SCI-Expanded, 1999–present) of Clarivate Analytics Web of Science Core Collection (WoSCC) is one of the most authoritative and comprehensive databases in various disciplines, comprising a wide range of academic journals and literature, and is widely used as the data source for bibliometric study (12). Literature on the AI studies of the four TCM diagnoses from the WoSCC was collected. Two researchers conducted an independent search to ensure accuracy and consistency, and the search period was from the inception of the database [1980] to October 1, 2022.

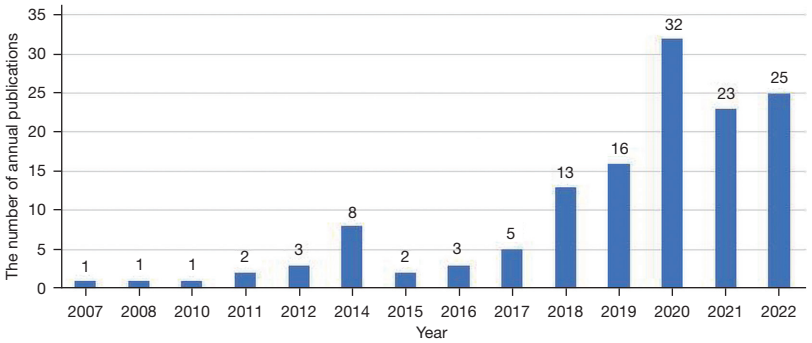

Figure 1 Annual number of publications involving artificial intelligence research on the four TCM diagnoses. TCM, traditional Chinese medicine.

The following search terms/parameters were applied: TS = ("tongue" OR "face" OR "pulse*" OR "symptom" OR "syndrome" OR "voice" OR "lip" OR "sublingual vein") AND ("TCM" OR "Traditional Chinese medicine" OR "Chinese medicine") AND ("deep learning" OR "machine learning" OR "artificial intelligence") AND Language = (English) (13). Data including titles, authors, keywords, citations, journals, institutions, and references of the publications were saved, and a total of 136 effective studies were obtained from 2007 to 2022.

Data analysis

First, the documents were imported to Citespace (version 6.1.R3, Drexel University, United States) to remove duplicates. Next, Microsoft Excel 2019 (Redmond, WA, USA) was used to conduct data aggregation and analysis, and VOSviewer software (version 1.6.18, https://www.vosviewer.com/, accessed on 15 Sep 22) was used to create the bibliometric networks (14). In this study, the retrieval characteristics of the four TCM diagnoses for AI included the distribution of publication years, regions, organizations, journals, core authors, keywords, and key references. For the co-authorship map, the authors, keywords, etc. were introduced into the software as a unit and linked to each other based on the number of joint articles and keywords. The results were displayed using density visualizations.

In the network visualization map, nodes formed clusters, which were characterized by colors, circles, lines, and the number of clusters. Different clusters have different colors; large circles indicated that terms were more important and closer clusters represented strong relationships. The line between the terms represented the relationship, with thicker lines denoting stronger correlations between the two terms (15). Citespace (version 6.1.R3) software was utilized to accomplish the timeline of co-citation analysis of the keywords and burst keywords. A free online platform (https://www.mapchart.net/) was used to conduct a map of the countries.

Results

Annual publications and trends

The annual number of papers published on AI in the four TCM diagnoses is shown in *Figure 1*. From 2007–2017, the number of papers published was fewer than 10, indicating a slow start to the study of the four TCM diagnostic methods by AI. From 2018, the number of papers published exceeded 10, with an overall upward trend. In particular, the highest number of articles was 32, which was achieved in 2020. Recently, AI studies on the four TCM diagnoses have received increasing attention.

Analysis of countries

We analyzed the national and regional characteristics of AI studies of the four TCM diagnostic methods. The results showed that among 15 countries that had published articles in this field, the majority of papers were from China (n=126), indicating a significant central tendency. Also, the United States and Canada were identified in more than five articles. *Table 1* summarizes the top 10 countries with the highest frequency. China, Canada, and the United States were the highest-ranked countries and had been cited more than 50 times. Despite this, Japan accounted for the highest number of citations per paper. Intelligence studies of the four TCM diagnoses were mainly distributed in Eastern

Table 1 Top 10 most productive countries with publications on the four TCM diagnoses

Rank	Countries	Number of articles	Total citations	Average citations
1	China	125	863	6.90
2	Canada	7	81	11.57
3	USA	7	86	12.29
4	India	5	15	3.00
5	Australia	4	19	4.75
6	South Korea	4	21	5.25
7	England	2	14	7.00
8	Germany	2	9	4.50
9	Italy	2	1	0.50
10	Japan	2	25	12.50

TCM, traditional Chinese medicine.

Asia, North America, and Europe, as shown in *Figure 2*.

Analysis of journals and conferences

The journals and conferences published on the study of the four TCM diagnostic methods were analyzed, and the characteristics of the journals and conferences, such as article numbers, total citation status, and average citation status, were recorded and quantified. Based on the data analysis, documents related to AI in the four TCM diagnoses published from 2007 to 2022 were distributed in 81 different journals and conferences. *Evidence-Based Complementary and Alternative Medicine* and *IEEE Access* published the most papers in this field, with more than 10 publications per journal. It is worth noting that the *2020 IEEE International Conference on Bioinformatics and Biomedicine* published four articles in this field (*Table 2*).

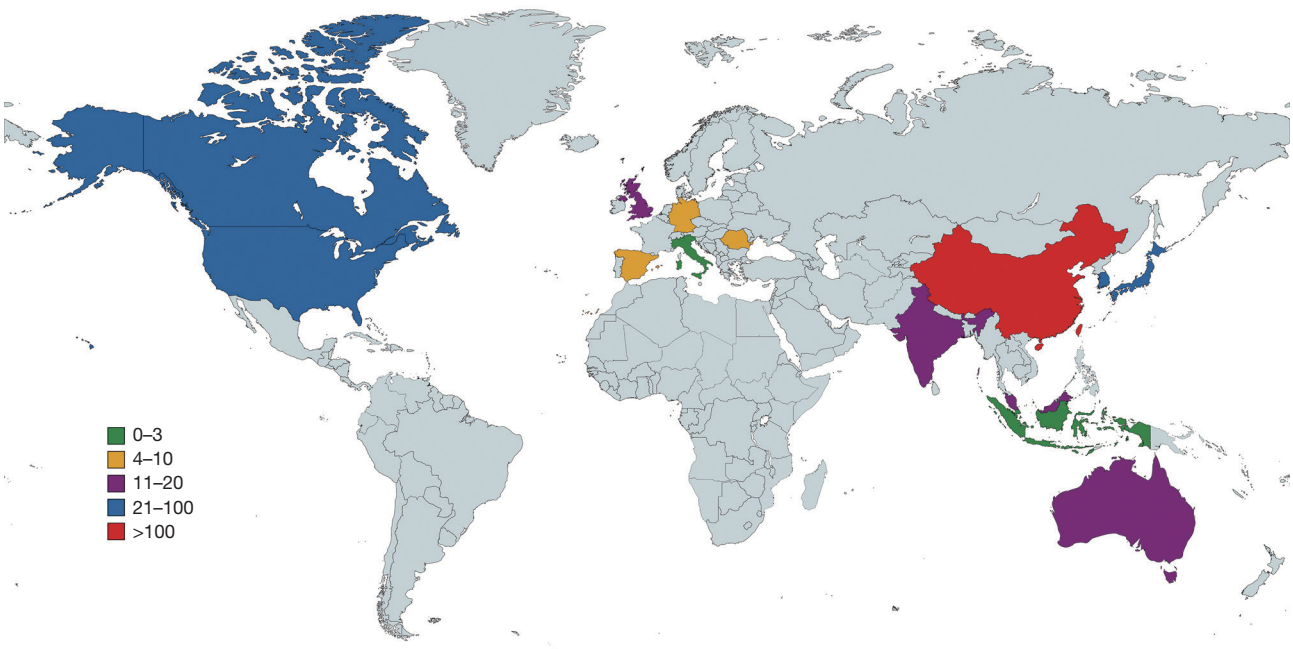

Figure 2 Country distribution map of the artificial intelligence research on the four TCM diagnoses. TCM, traditional Chinese medicine.

Table 2 Top 11 journals with more than three published articles in the field of artificial intelligence research on the four TCM diagnoses

Rank	Journal title	Number of articles	Total citations	Average citations
1	*Evidence-Based Complementary and Alternative Medicine*	10	70	7.00
2	*IEEE Access*	10	66	6.60
3	*JMIR Medical Informatics*	6	27	4.50
4	*Biomed Research International*	5	54	10.80
5	*Concurrency and Computation-Practice & Experience*	5	41	8.20
6	*2020 IEEE International Conference on Bioinformatics and Biomedicine*	4	5	1.25
7	*Computational and Mathematical Methods in Medicine*	4	35	8.75
8	*Journal of Healthcare Engineering*	4	2	0.50
9	*Artificial Intelligence in Medicine*	3	82	27.33
10	*European Journal of Integrative Medicine*	3	32	10.67
11	*Multimedia Tools and Applications*	3	12	4.00

TCM, traditional Chinese medicine.

The VOSviewer visualization map of the most commonly cited journals related to AI in the four TCM diagnoses showed that of the 1,919 cited journals, 45 met the threshold (the minimum number of citations of a source was 15). As shown in *Figure 3*, the co-citation network of the journal consisted of three clusters: red, blue, and green. The IEEE *Conference on Computer Vision and Pattern Recognition (CVPR IEEE)* had a total of 133 citations, which was higher than that of any other conference or journal. Notably, the *Evidence-Based Complementary and Alternative Medicine* journal had the highest number of citations among the journals (126 times). In the three clusters, the red cluster journals were mainly in the field of TCM, focusing on the application of AI in TCM, and articles mainly cited these journals to analyze and review existing research and provide empirical support for their own research. Green was mainly comprised of journals in the IEEE field, and these are often technical journals. Moreover, the blue cluster journals were mainly general and neurological journals, and the purpose of citing these journals was mainly to provide technical support. Each point in the density visualization has a color that indicates the density of the journal; the larger the number of journals in the neighborhood of a point and the higher the weights of the neighboring journal, the closer the color of the point is to yellow (*Figure 4*).

Analysis of authors

A total of 652 authors participated in the publication of papers on AI in the four TCM diagnostic methods. *Table 3* lists the authors who published more than four articles. The most productive authors were mostly from China. Xiaojuan Hu, Jiatuo Xu, and Liping Tu were the top-three ranked authors, with 9, 9, and 8 papers respectively. Meanwhile, although Jinhong Guo and Weihong Li published fewer papers, their average citations were as high as 23.75 and 22.75, respectively. *Figure 5* displays the analysis results of the cooperative network among authors who had published at least one paper. The size of the circle in the figure indicates the extent of the author's cooperation, the width of the line connecting the authors indicates the strength of cooperation, and the color indicates the cluster network of the subgroups. The collaborative network of authors in AI studies of the four TCM diagnoses presents the trend of centralized characteristics and regional concentration.

Moreover, cluster analysis identified seven cluster cooperative teams. Among them, Longtao Cui, Zhifeng Zhang, and Jiatuo Xu were considered high-yielding scholars with greater influence. A co-citation (cited authors) visualization map was also generated using VOSviewer software. A total of 39 authors who met the threshold (the minimum number of citations of an author was set to 10) were identified among 2,864 authors. Through analysis of co-citation (cited authors), we classified the main authors in the field of AI for the four TCM diagnostic methods according to this "distance". We observed that Zhang B, He KM, and Wang XZ had made significant contributions to AI for the four TCM diagnoses (*Figure 6*).

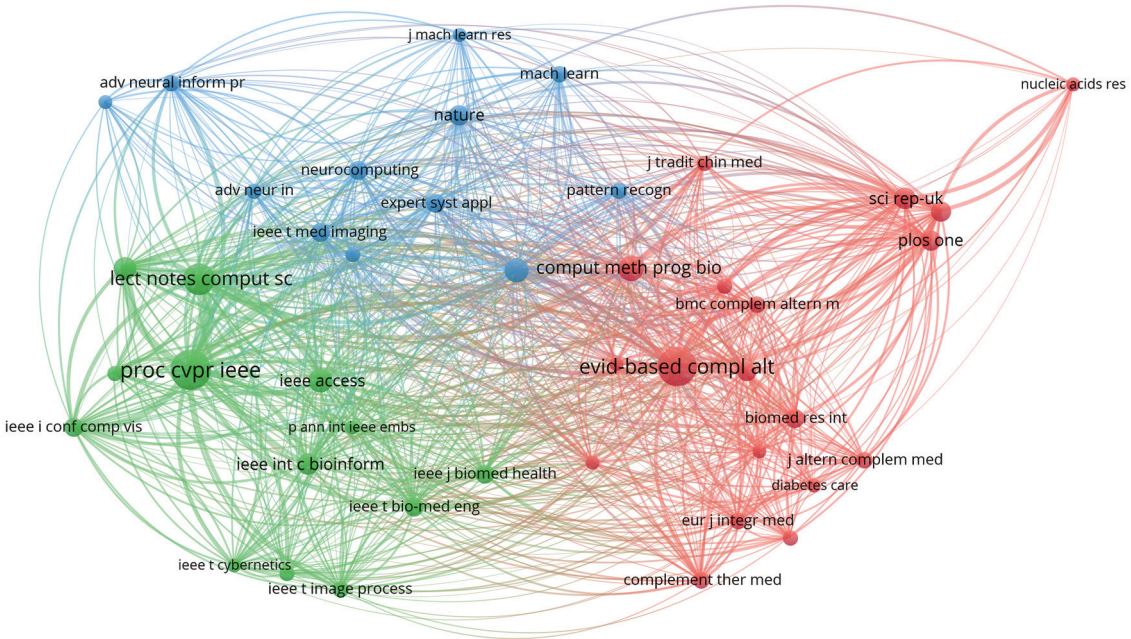

Figure 3 Co-citation network of the most commonly cited journals and conferences. Among the 1,919 cited journals, 45 met the threshold (minimum of five citation sources).

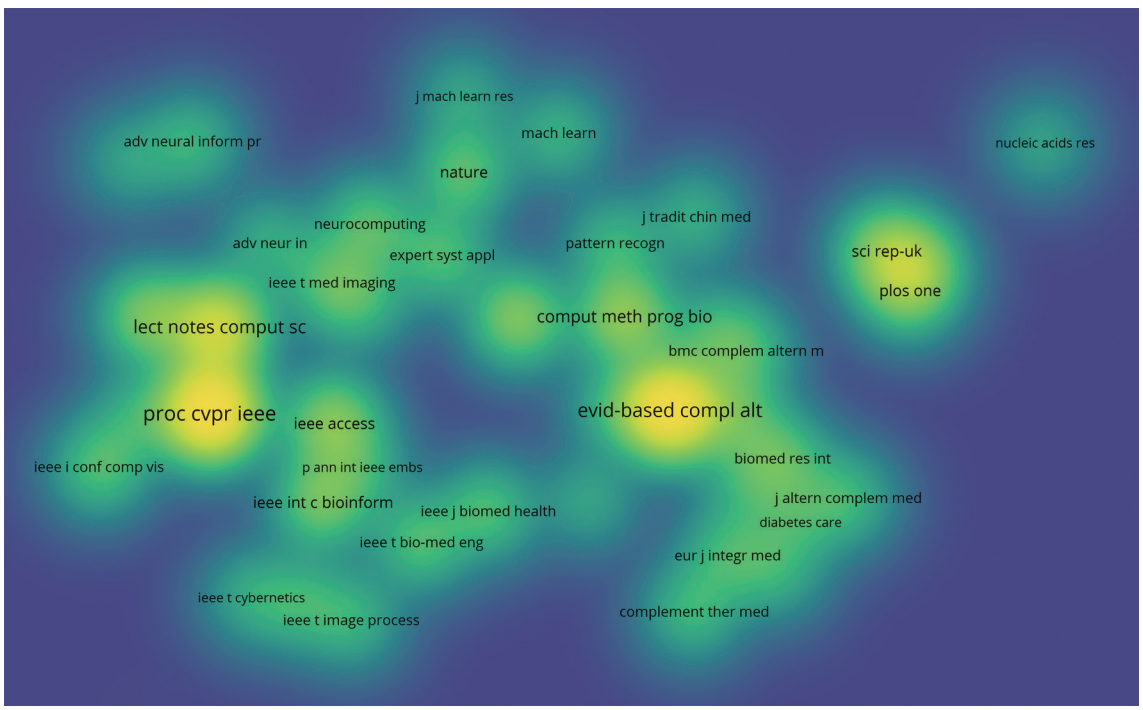

Figure 4 The density map of the most commonly cited journals. Dark yellow represents journals with large numbers of citations.

Table 3 The top 16 core authors of publications on artificial intelligence research for the four TCM diagnoses

Rank	Author	Documents	Citations	Average citations
1	Xiaojuan Hu	9	85	9.44
2	Jiatuo Xu	9	84	9.33
3	Liping Tu	8	82	10.25
4	Ji Cui	6	59	9.83
5	Guihua Wen	6	33	5.50
6	Zhikui Chen	5	61	12.20
7	Jun Li	5	27	5.40
8	Changchuan Bai	4	71	17.75
9	Longtao Cui	4	26	6.50
10	Jinhong Guo	4	95	23.75
11	Jingbin Huang	4	26	6.50
12	Tao Jiang	4	33	8.25
13	Peng Li	4	61	15.25
14	Weihong Li	4	91	22.75
15	Qingchen Zhang	4	71	17.75
16	Change Zhou	4	26	6.50

TCM, traditional Chinese medicine.

Analysis of the institutions and funding agencies

A total of 200 institutions participated in publishing research papers on AI for the four TCM diagnoses. The most productive institutions among the top 10 were the Shanghai University of Traditional Chinese Medicine, followed by Xiamen University and the China Academy of Chinese Medical Sciences. The top 10 ranked institutions were all Chinese. There were five TCM institutions in the top 10 but the total number of citations of the TCM institutions (n=343) was lower than that of non-TCM institutions (n=372), as shown in *Table 4*.

Figure 7 illustrates the cooperation network analysis of institutions that published at least two articles. The size of the circle indicates the degree of institutional cooperation, the width of the line between the connecting mechanism indicates the cooperation strength, and the color indicates the cluster network of subgroups. Eight key cooperation clusters were identified. In addition, the organizations with the most citations included the Shanghai University of Traditional Chinese Medicine, Xiamen University, and the University of Science and Technology of China. Furthermore, the node in light purple indicated that the Shanghai University of Traditional Chinese Medicine had a higher number of citations than any other organization, suggesting that it might be a very important institution for the study of AI in the four TCM diagnoses (*Figure 8*).

Funding often plays a role in reflecting the attention that certain areas of research have received and represents the development of available scientific resources in that field of research. *Figure 9* summarizes the top 10 funding agencies by publication. We found that all of the funding agencies were from China. The National Natural Science Foundation of China is the most funded agency (n=40). From a regional perspective, Guangzhou (n=10) and Shanghai (n=6) were the most funded regions in China (n=10).

Analysis of the keywords

A total of 43 keywords with a frequency of at least three times were retrieved from among 503 keywords. Six clusters were generated based on their association using VOSviewer software. The top keywords in each cluster are listed in *Table 5* and the visualization map of the keywords is shown in *Figure 10*. Cluster 1 consisted mainly of "traditional Chinese medicine", "machine learning", "diagnosis", "syndrome differentiation", and "natural language processing". This cluster mainly expressed the research progress of AI in TCM diagnosis and symptom classification (red). Cluster 2 focused on "deep learning", "tongue segmentation", and "feature extraction"; it mainly introduced the application of deep learning in tongue image processing (green). Cluster 3 focused on "algorithm", "diseases", "smart Chinese medicine", and "model". This cluster mainly constructed models of TCM-related diseases (blue). Cluster 4 focused on "neural network" and "tongue image classification"; studies in this cluster focused on tongue image classification based on the neural network (yellow). Cluster 5 focused on "deep transfer learning", "representation learning", and "tongue image"; it primarily researched the application of different AI methods in TCM diagnosis (purple). Cluster 6 focused on "tooth-marked tongue", "image-analysis", and "tongue diagnosis". This cluster primarily researched the application of different AI methods in TCM diagnosis (purple), as well as the association between the tooth-marked tongue and TCM diagnosis (sky blue).

The keyword timeline graph was developed to depict

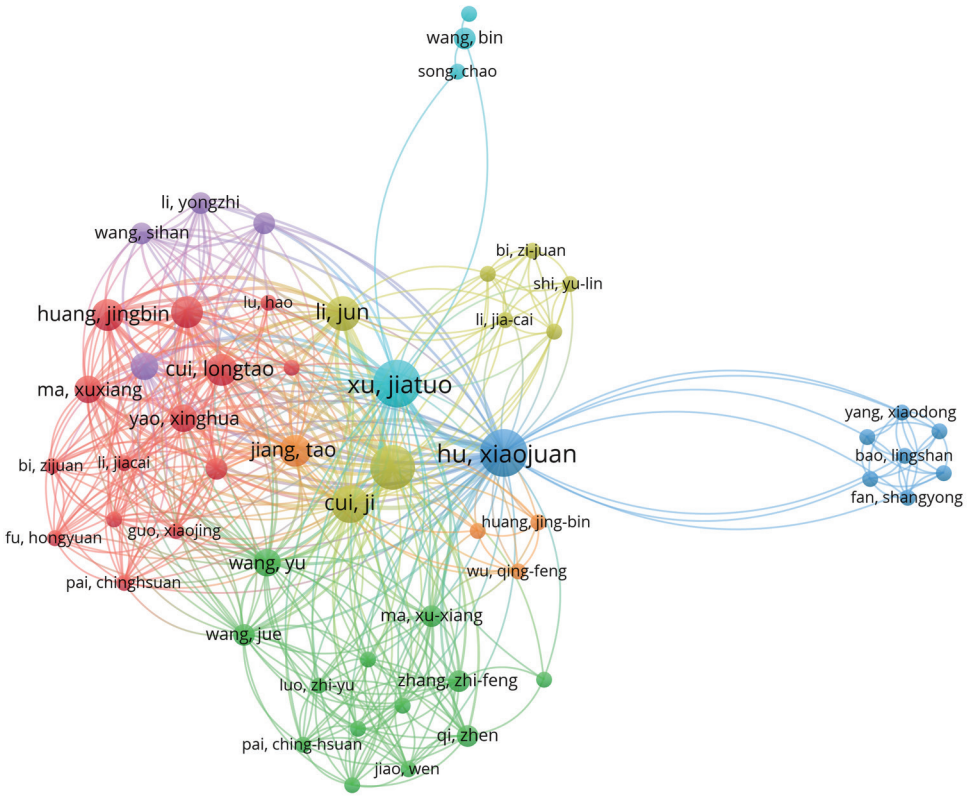

Figure 5 Visualization map of the collaborative network of authors in artificial intelligence studies of the four TCM diagnoses. TCM, traditional Chinese medicine.

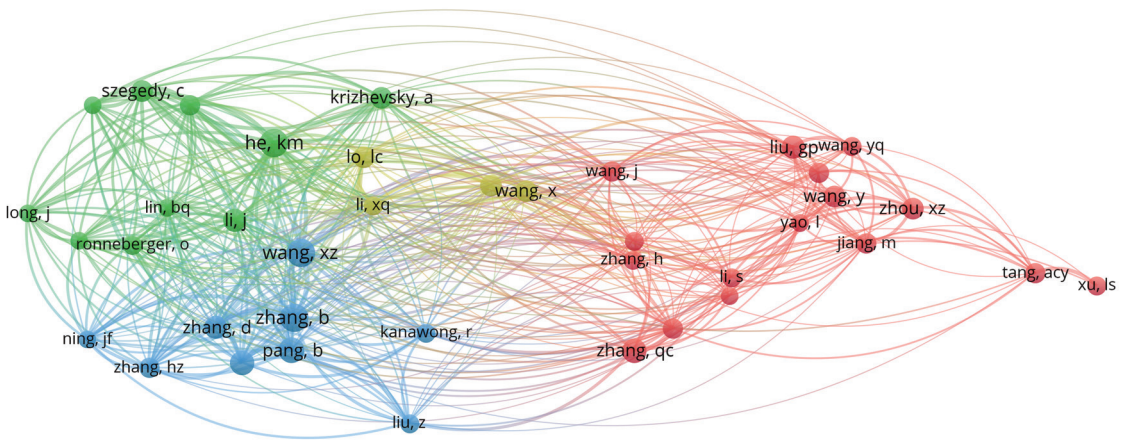

Figure 6 Visualization map of co-citation (cited authors).

the relationships and occurrences of keywords related to the search topics. An overlay visualization timeline graph of the keywords was generated using Citespace software to explore the occurrence in AI for the four TCM diagnoses over a period of time (*Figure 11*). All keywords were marked according to the sequence of keyword appearance. Notably, in 2007, "tongue diagnosis", "deep learning", and "machine learning" appeared in the visualization map. Compared with

Table 4 The top 10 most productive institutions in the artificial intelligence research on the four TCM diagnoses

Rank	Organizations	Documents	Citations	Average citations
1	Shanghai University of Traditional Chinese Medicine	18	135	7.50
2	Xiamen University	11	65	5.91
3	China Academy of Chinese Medical Sciences	9	40	4.44
4	University of Science and Technology of China	7	133	19
5	Tsinghua University	7	80	11.43
6	Chengdu University of Traditional Chinese Medicine	6	121	20.17
7	Beijing University of Traditional Chinese Medicine	6	11	1.83
8	South China University of Technology	6	33	5.5
9	Fujian University of Traditional Chinese Medicine	5	36	7.2
10	Dalian University of Technology	5	61	12.2

TCM, traditional Chinese medicine.

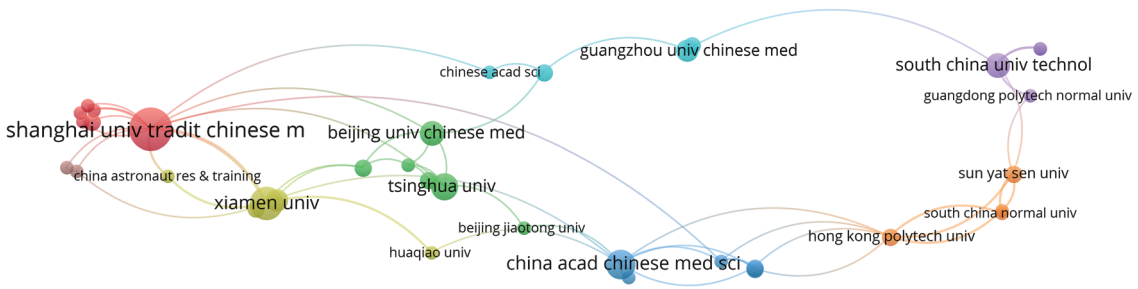

Figure 7 The organizations cooperation network related to artificial intelligence research for the four TCM diagnoses. TCM, traditional Chinese medicine.

the AI-related keywords, such as "representation learning", "extreme machine learning", etc., TCM keywords including "pulse signal", etc. appear later, indicating that the research on AI for the four TCM diagnoses has increased in recent years. We believe that the study of AI-based TCM diagnosis has research value and will become a hotspot in TCM research in the future.

The top 10 keywords with the strongest citation bursts were listed in *Figure 12*. Among these, "machine learning", the earliest keyword burst, was detected in 2007. Subsequently, research related to AI, such as "information fusion", became hot topics. A hot topic related to TCM diagnosis, "syndrome differentiation", first appeared in 2008, followed by "tongue shape classification" in 2012. The most recent keywords burst ("neural network" and "image segmentation") occurred in 2019, suggesting that AI-related neural networks are attracting increased attention in the study of tongue images and might become new research hotspots in the next few years.

Discussion

The four TCM diagnostic methods mainly include looking, smelling, asking, and touching. In this study, we used bibliometrics to analyze the literature related to AI for these four TCM diagnoses. The results showed that relevant literature only began to appear in 2007. Over the past 15 years, the literature on AI for the four TCM diagnoses increased every year (*Figure 1*).

The number of papers published is an important indicator of the level of relevant scientific research of countries or institutions. Country analysis showed that China published the highest number of AI papers on the four TCM diagnoses (*Table 1* and *Figure 2*), indicating that

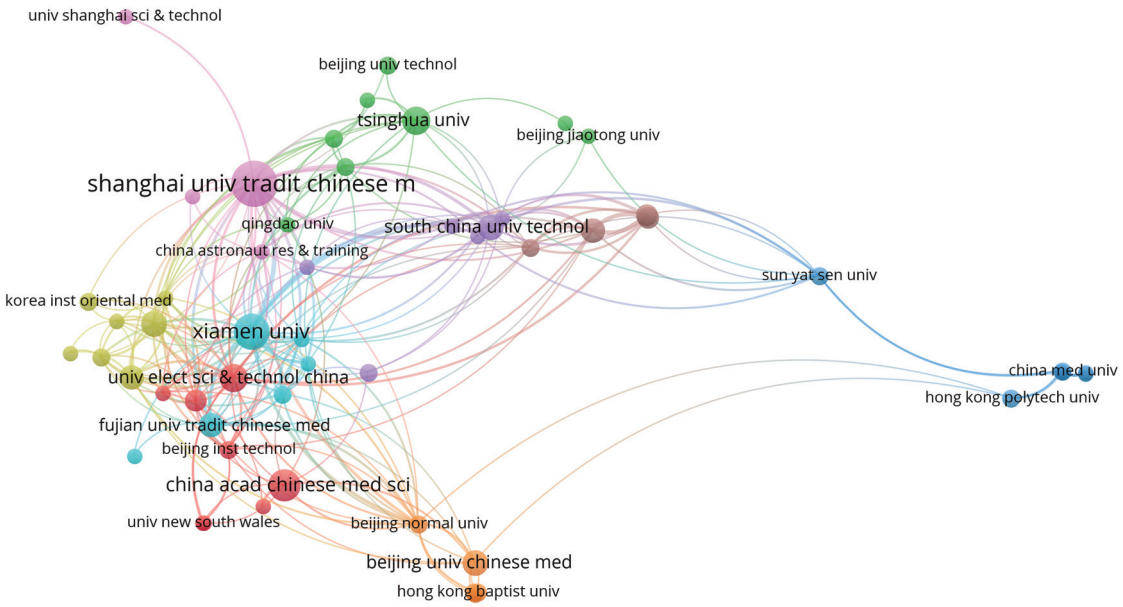

Figure 8 The organizations co-citation network (cited authors) related to artificial intelligence research for the four TCM diagnoses. TCM, traditional Chinese medicine.

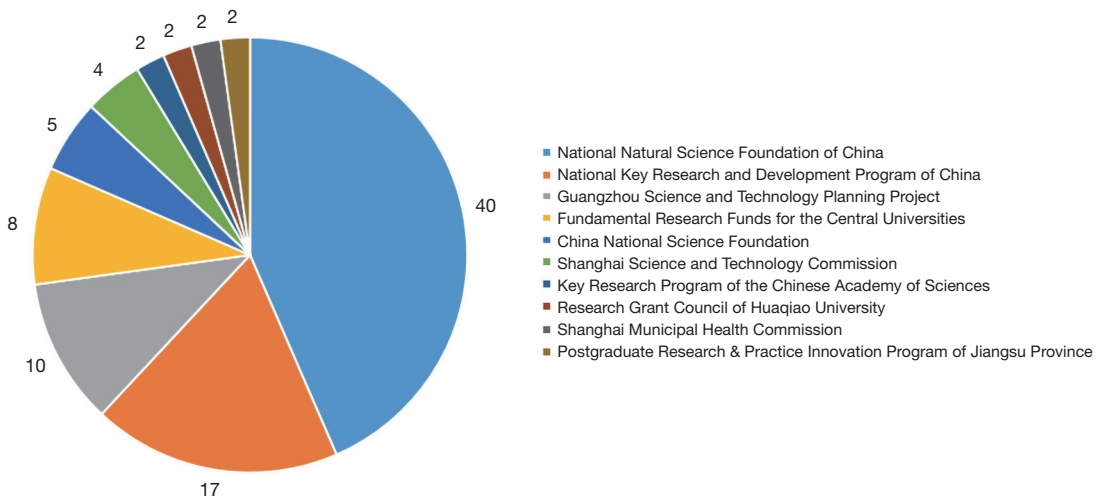

Figure 9 The top 10 funding agencies with the highest frequency related to artificial intelligence research for the four TCM diagnoses. TCM, traditional Chinese medicine.

China is highly influential in this field. The number of citations is often used to measure impact (16); the average citation per paper in China was unsatisfactory, with a lower number of average citations than in Japan, the USA, and Canada. China also lacked highly cited articles, which may lead to insufficient international influence in the future. As for countries/regions cooperation, China was the center of research. However, most research were limited to Europe and a few Asian countries, such as Japan, South Korea. Therefore, cross-country and regional cooperation was essential in the future, especially with South America and Africa. This phenomenon may be influenced by culture, but also closely related to the level of the economy. It was therefore necessary to strengthen national and regional

Table 5 Six clusters of keywords on artificial intelligence research for the four TCM diagnoses

Clustering number	Color	Number of articles	Hotspot trend
Cluster 1	Red	Artificial intelligence, classification, data mining, diagnosis, feature selection, machine learning, medicine, natural language processing, prediction, syndrome differentiation, system, traditional Chinese medicine	AI in TCM diagnosis and TCM symptom classification
Cluster 2	Green	Deep learning, feature extraction, image, segmentation, task analysis, tongue segmentation	Application of deep learning in tongue image processing
Cluster 3	Blue	Algorithm, diseases, hypertension, model, smart Chinese medicine	Models of TCM-related diseases
Cluster 4	Yellow	Color, convolutional neural network, image classification, tongue image classification, tongue images	Neural networks are classified with tongue images
Cluster 5	Purple	Covid-19, deep transfer learning, representation learning, tongue image	Deep transfer learning and tongue diagnosis
Cluster 6	Sky blue	Image-analysis, tongue diagnosis, tooth-marked tongue	Tooth-marked tongue

TCM, traditional Chinese medicine; AI, artificial intelligence.

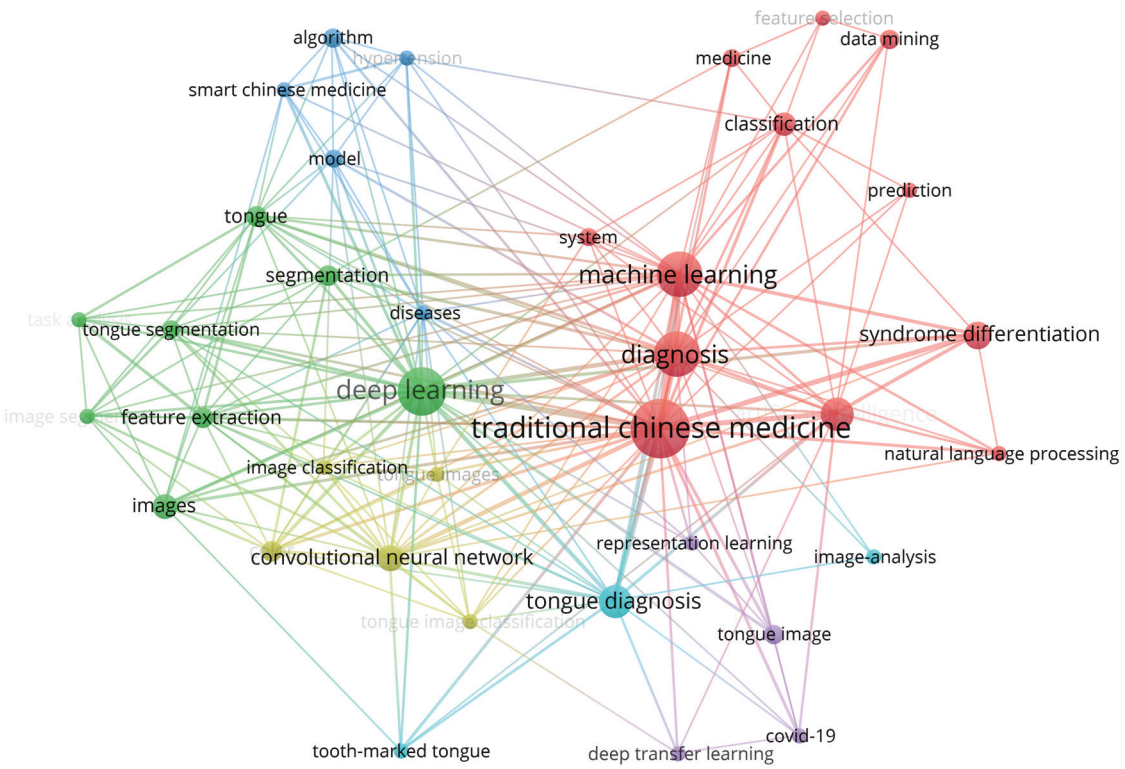

Figure 10 Keywords clustering visualization map in the field of artificial intelligence research for the four TCM diagnoses. TCM, traditional Chinese medicine.

cooperation, particularly with those developing countries.

Determining the importance of a journal provides researchers with reliable reference information and identifies target journals for their literature searches and submissions (17). According to the results, among the 81 journals/conferences involved in this study, most journals are biological, engineering, and computer journals, as shown in *Table 2*. Our results showed that the *Evidence-Based*

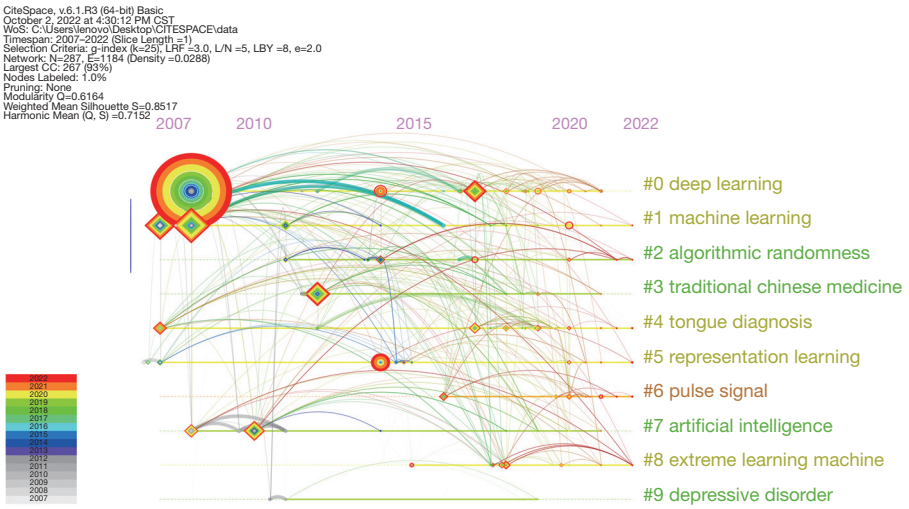

Figure 11 Network visualization map of the timeline of co-citation keywords in the field of artificial intelligence research for the four TCM diagnoses. TCM, traditional Chinese medicine.

Top 10 Keywords with the strongest citation bursts

Keywords	Year	Strength	Begin	End	2007–2022
Machine learning	2007	0.95	2007	2008	
Syndrome differentiation	2007	1.81	2008	2011	
Information fusion	2007	1.35	2010	2011	
Artificial intelligence	2007	1.1	2010	2011	
Tongue shape classification	2007	1.05	2012	2017	
Diagnosis	2007	1.02	2012	2014	
Classification	2007	1.55	2014	2015	
Convolution neural network	2007	1.14	2017	2018	
Image segmentation	2007	1.02	2019	2020	
Convolutional neural network	2007	0.98	2019	2020	

Figure 12 Visualization map of the top 10 keywords with the strongest citation bursts in the field artificial intelligence research for the four TCM diagnoses. TCM, traditional Chinese medicine.

Complementary and Alternative Medicine and *IEEE Access* journals published the highest number of papers, indicating that most articles related to AI for the four TCM diagnoses would be considered for publication in this journal. In terms of conference documents, the *2020 IEEE International Conference on Bioinformatics and Biomedicine* published the most papers, illustrating that this field was a particular focus in the engineering field.

In the author/co-authorship analysis, Xiaojuan Hu and Jiatuo Xu have the most published literature among the 652 authors who published papers related to AI for the four TCM diagnostic methods (*Table 3*). Furthermore, Xiaojuan Hu, Jiatuo Xu, Liping Tu, and Ji Cui maintained a very close relationship and published a large amount of literature on group cooperation (*Figure 5*). It is worth noting that although Jinhong Guo and Weihong Li published fewer than five papers, their average number of citations exceeded 20, highlighting the importance of their articles in this field. The visualization map of co-citation showed that no representative authors or experts have yet emerged in

this research area. Therefore, we believe that these top teams will publish representative papers in this field by strengthening cooperation with each other.

The top 10 most productive institutions were all from China, of which five belong to TCM institutions, two were comprehensive institutions, and three were science and technology institutions (*Table 4*). In addition, the Shanghai University of Traditional Chinese Medicine published the most AI-related papers on the four TCM diagnoses [the red node represents the Shanghai University of Traditional Chinese Medicine, and the purple node denotes institutions that were cited more often (*Figure 7*)]. From the distance of the points, we observed that research institutes in this field are scattered. Although the top 10 institutions in terms of production were all in China, they did not have close cooperation with each other, and it is more noteworthy that they had little cooperation with foreign institutions. Therefore, China's academic institutions should strengthen cooperation to achieve the purpose of improving academic influence. Through the analysis of funding, it was concluded that the National Natural Science Foundation of China sponsors the most research in this field (*Figure 9*). The other regions with more sponsorship were first-tier cities and regions in China, which showed that research in this field has not attracted attention in other regions of China.

Keywords can provide up-to-date information about the themes in a particular study. In this analysis, we highlighted the network of keywords connected by co-occurrence (18), and six research clusters were generated based on their association. As shown in *Figure 10*, in the center of the network map were high-frequency keywords, mainly including "traditional Chinese medicine", "deep learning", and "tongue diagnosis", etc. The keywords of these centers reflect that deep learning research related to tongue diagnosis in AI for the four TCM diagnoses was an interesting research hotspot.

In this paper, the timeline map on how keywords change over time was also analyzed. At the top of the figure, we observed that research in this area first appeared in 2007, five different machine learning techniques were used to classify the tongue texture and tongue coating (19), and the SVM machine learning method had the best performance. The nodes on the left abscissa represent the migration behavior of the research hotspots, and the lines between them denote citing. During the middle stage, articles on AI for the four TCM diagnoses mainly focused on the updating and evolution of methodology. For example, they proposed a supervised machine learning technique based on the shape of a tongue image to recognize diseases (20), explored new methods for the clinical characterization of ZHENG using various machine learning algorithms, ZHENG is equivalent to syndrome, which is the basic unit and foundation of TCM treatment, and there were also some studies on tongue color and facial features, etc. (21,22). In the most recent stage. In addition to the previous research on the tongue, there were also more studies on the pulse and TCM symptoms (8,23-28).

Burst detection is an algorithm developed to determine the sharp increase in citation or keyword popularity within a limited period of time, and can be used as an effective method of identifying hot spots (12). Our research showed that the first detected keyword was "machine learning" in 2007. Since 2008, the keyword "syndrome differentiation" related to TCM began to appear. From 2010 to 2020, keywords related to machine learning, such as "information fusion", "classification", etc., began to appear. It is worth noting that the keyword "tongue shape classification" lasted for 6 years from 2012 to 2017.

TCM adheres to a "people-oriented" principle and emphasizes prevention. While inheriting and further developing its characteristics, TCM comprehensively combines modern technology and technology to maximize its advantages, so as to promote the objectification, standardization, and accuracy of TCM according to the "holistic concept" and "treatment based on syndrome differentiation". The four TCM diagnostic methods are the primary means of disease differentiation and treatment in TCM. In recent years, with the rapid development of AI technology, the four diagnoses of TCM have also achieved fruitful results. At present, the problems of intelligent research on the four diagnostic methods of TCM include the lack of accurately labeled datasets, the limited generalizability of feature extraction, and the lack of intelligent research on the fusion of the four diagnostic approaches (29).

Currently, research on monitoring intelligence is relatively mature and ideal. The intelligent process can be divided into several steps, including image acquisition, image preprocessing, image segmentation, feature extraction/selection and classification, and recognition. Research on AI in TCM is mainly concentrated in the fields of eye, tongue, and face diagnoses. To solve the problem of prescription sample imbalance, Xi *et al.* (30) proposed algorithm that combines machine learning to obtain more accurate and stable results. Based on computer vision and AI

technology, body mass identification and disease diagnosis are carried out by respectively observing the images of the eyes, tongue, and face. Numerous scholars have also proposed various intelligent solutions based on fundus image segmentation and disease diagnosis and prediction (31).

In addition, many scholars have focused on the algorithm research of tongue and face segmentation and classification. There are intelligent face diagnosis machines that can classify signs by objectification and intelligent complexion, facial gloss, and lip color. Also, intelligent tongue instruments can diagnose TCM syndromes according to the characteristics of tongue color, shape, and coating, and intelligent eye diagnostic instruments for analysis and health assessment according to the characteristics of scleral spots and blood vessels (32,33). Olfactory diagnosis is divided into two categories: acoustic diagnosis and olfactory diagnosis. It is usually studied through the collection, preprocessing, feature extraction, and pathological diagnosis of sound or odor signals, and relies on the development of intelligent auscultation and olfactory diagnostic instruments. At present, the intelligent research of olfaction is still mainly in the academic theory exploration stage. Existing smart sniffing technology can perform gas sampling, oral exhalation analysis, gas composition analysis, and disease diagnosis. Scholars have mainly utilized odor identification intelligent technology for the diagnosis of asthma, cancer, tuberculosis, and other diseases (34).

The AI consultation system can provide efficient and convenient TCM consultation services, which usually involve two aspects: input/output equipment and an intelligent diagnostic model, and can be presented on a smartphone, computer web page, etc. Here, technical implementation is mainly divided into two steps: quantification of the patient's symptoms and intelligent diagnosis. Human-computer interactive voice question answering refers to the user describing their body condition through speech, obtaining semantic information through natural language processing, and then performing intelligent analysis and disease diagnosis. The intellectualization of TCM emphasizes the intellectualization of research under the guidance of TCM theory and uses AI technology to achieve clinical diagnostic evaluation and daily health care with TCM. In recent years, emerging deep learning algorithms can process unstructured data such as images, audio signals, texts, etc., in a method that is consistent with the principle of the four TCM diagnoses. In the field of TCM research, the four diagnostic parameters based on AI can be regarded as a multi-modal fusion method. At present, there are some common problems in TCM diagnostic methods, such as the use of collection instruments are not uniform, the format and size of the pictures are different, so the collection process and collection instruments of TCM tongue image and pulse information need to be stipulated by relevant national or industry standards, laying the foundation for the processing of big data of the four diagnoses of TCM in the future.

AI-assisted pulse diagnosis can be used to distinguish pregnancy or diagnose various diseases, including gastritis, cholecystitis, pancreatitis, duodenum, bulbar ulcer, acute appendicitis, hypertension, coronary heart disease, diabetes mellitus, acute appendicitis, arteriosclerosis, and cirrhosis, and can also be employed to quantitatively assess the risk of certain diseases (8,35). However, the reliability of AI-assisted pulse diagnosis needs to be improved, and thus, it is more suitable for assisting doctors in diagnosis rather than independently identifying the syndromes or diseases of patients (36). AI-assisted consultation is mainly based on data analytical methods, including SVM, neural networks, graph models, multi-label learning, and so on. The multi-label learning method can be used to mine data and construct an intelligent consultation model, and its classification accuracy of coronary heart disease is up to 78% (37). Some scholars have utilized the complex system and probability graph model to model and divide the consultation data and determine its average value for chronic gastritis, with an accuracy of up to 82.5% (38). On the other hand, there are problems associated with the application of AI technology in the field of TCM diagnosis. Firstly, the superficial form of TCM AI cannot enable technology empowerment, nor does it conform to the TCM theory, which makes it difficult to be used in clinical practice. Thus, it is necessary to adjust the direction of technology integration and TCM to promote deep integration. Secondly, the TCM diagnostic process simulated by AI is overly complex and comprehensive, which requires further theoretical decomposition and interpretation before it can be recognized and measured by modern technology. A unified glossary is needed to improve the objectification and standardization of TCM diagnosis.

Conclusions

Through the analysis of keywords and timeline maps, the diagnosis and classification of related diseases based on deep learning algorithm and neural network of tongue

images will still be a hotspot in future research, but in addition to these studies, AI research on clinical ZHENG and symptoms of TCM will rise in the future and become research trends. The advantages of introducing AI technology into TCM diagnosis include its objectified, quantified, and precise data output and diagnostic results, as well as the fact that it can use scientific and standard "universal" language to diagnose and predict diseases and spread TCM. Finally, we firmly believe that through further technical decomposition and elucidating the needs of TCM AI-assisted diagnosis, the cross-integration of TCM and AI technology can be promoted.

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Footnote

Conflicts of Interest: All authors have completed the ICMJE uniform disclosure form (available at https://atm.amegroups.com/article/view/10.21037/atm-22-6431/coif). The authors have no conflicts of interest to declare.

Ethical Statement: The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

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