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Research on the coupling measurement of medical education and health resource allocation under the background of healthy China

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Abstract

Objective To analyze the coupling and coordination level of medical education and health resource allocation in China, and to provide scientific basis for promoting the high-quality development of medical education and the efficient allocation of health resources.

Methods Based on the panel data from 2011 to 2021, the coupling coordination degree model was used to measure the coupling coordination index of medical education and health resources in China. The spatial auto-correlation model was used to analyze the development status and distribution characteristics of the coupling coordination degree of the two systems. The kernel density estimation method was used to analyze the dynamic evolution trend of the coupling coordination of the two systems. The QR quantile regression model was used to explore the key factors affecting the coupling coordination degree of the two systems.

Results During the observation period, the coupling coordination degree of the two systems increased from 0.393 to 0.465, with a growth rate of 18.3%. The coupling coordination degree between regions gradually decreased in the eastern-central and eastern-western regions, and there were still large differences between the central and western regions. The coupling coordination degree of the two systems in the region was significantly different in the eastern and western regions, and the central region was relatively similar. There is a positive spatial correlation between the provinces, and 25.81% of the provinces have transitions. Finally, the number of points in the first and third quadrants is higher than that in the second and fourth quadrants. In the process of dynamic distribution, the degree of polarization of the coupling coordination degree curve of the two systems is gradually weakened. Per capita GDP, residents ' income difference and population size are the positive and significant factors driving the coupling and coordinated development of the two systems.

Conclusion The coupling and coordination degree of the two systems of medical education and health resource allocation showed a stable upward trend during the observation period, and the global spatial positive correlation also gradually increased, showing the spatial agglomeration characteristics of ' high-high agglomeration ' and ' low-low agglomeration '. The spatial difference of coupling coordination degree shows a shrinking trend and develops towards equalization. The coupling coordination degree of the two systems is affected by social, economic and demographic factors to varying degrees. Therefore, it is necessary to innovate the coordinated development

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mechanism of the two systems, promote the two-way flow of medical education and health resource allocation in talents, technology and other elements, and then promote the coupling and coordinated development of the two systems.

Keywords Medical education, The allocation of health resources, The coupling coordination, Time and space dynamic evolution

The distribution of health resources plays a crucial role in fostering the growth of healthcare service capabilities, with medical education serving as the primary resource [1]. Medical education encompasses the deliberate and organized educational activities aimed at nurturing medical and healthcare professionals in response to societal demands. Serving as a crucial method for developing medical professionals, it spans from foundational knowledge to hands-on clinical experience. The curriculum and instructional approaches in medical education play a significant role in shaping the objectives, framework, and proficiency of healthcare professionals [2]. The Ministry of Education and other relevant departments have proposed that China should expedite the establishment of a high-quality medical education system, enhance the equity of medical education, accelerate the balanced growth of medical education resources, optimize the distribution of regional medical education resources [3], facilitate the seamless integration of undergraduate medical education, postgraduate medical education, and continuing medical education, and strive to enhance the quality of college education, advance postgraduate education, and ensure comprehensive coverage of continuing education. These efforts are essential to promoting the high-quality advancement of medical education, aligning with the common goals outlined in the '14th Five-Year Plan' to fully support the 'Healthy China' strategy and the effective implementation of the 'talent power' strategy [4]. The allocation of health resources involves distributing resources to various sectors, areas, and populations in a fair and efficient manner to address the health needs of the public. Currently, global health resource allocation encounters several challenges, including disparities in resource distribution, significant urban–rural disparities, and variations in service quality. Enhancing the allocation of health resources and optimizing resource utilization efficiency are crucial issues in the global health sector [5, 6]. With the advancement of the 'Healthy China 2030' plan outline [7], optimizing the medical and health service system, innovating the medical and health supply model, and improving the medical level and quality have become crucial focal points for the efficient and rational allocation of health resources. Medical education plays a vital role in cultivating high-level health literacy talents and providing health human resources, scientific and technological achievements, and social services to advance the development of China's healthcare initiatives and overall societal progress [8]. In order to ensure fair and equitable access to medical and health services and achieve the goal of 'basic medical and health services for all,' it is crucial to optimize the rational allocation of health resources [9]. Promoting the coordinated development of medical education and health resource allocation has a profound impact on actively responding to the Healthy China strategy and promoting the high-quality development of medical education.

By 2022, the scale of higher education in China will further expand to 46.55 million, with a gross enrollment rate of 59.6%. At the same time, the number of medical undergraduate enrollment in China is also growing steadily, with an average annual growth rate of 8.04%. Higher medical education in China is facing great challenges, especially the cultivation of high-quality and high-level applied medical technology professionals has become one of the important tasks to be solved urgently in colleges and universities.In recent years, as the country pays more and more attention to the development of medical and health undertakings, the people 's demand for medical services has also increased, which requires medical institutions to continuously improve the service level and quality level to meet the needs of the majority of patients. At the same time, the number of medical college graduates in China is increasing year by year. At present, graduated medical students have become an important force in health human resources. By the end of 2021, the total number of staff in China 's medical and health industry has reached 13,983,000, an increase of 508,000 compared with the previous year, with a growth rate of 3.8%, effectively alleviating the long-term shortage of talents in China 's medical and health care.The average life expectancy of Chinese residents has increased from 77.93 years in 2020 to 78.2 years in 2021. At the same time, the maternal mortality rate decreased from 16.9 / 100,000 to 16.1 / 100,000, and the infant mortality rate also decreased from 5.4 ‰ to 5.0 ‰. The above data clearly show that the ability and quality of medical services in China have been significantly improved. At the same time, it is inseparable from the rapid development of medical education in China, the continuous

updating of education and teaching concepts, and the continuous innovation of education models.

The high-quality and balanced development of health resources has always been a hot issue concerned by scholars at home and abroad, and the high-quality development of medical education is a booster to promote the rational allocation of health resources.Under the guidance of the global standards for medical education formulated by the World Federation for Medical Education (WFME), China 's medical education has achieved substantial equivalence with the quality assurance of international medical education, which plays an important supporting role in the improvement of medical and health service capabilities and high-quality economic development.In recent years, the research of foreign scholars has focused on the improvement of medical education quality and the innovation of teaching methods. In terms of improving the quality of education, foreign scholars have emphasized the importance of education evaluation. A scientific and objective education evaluation mechanism can accurately reflect the students ' learning situation and teaching effect, so as to provide strong support for teaching improvement [10]. To this end, scholars have actively advocated the construction of a comprehensive education evaluation system, which should cover multiple dimensions such as curriculum setting, teaching methods, and faculty to comprehensively ensure the quality and effectiveness of medical education. Through such a system, we can better diagnose the problems reflected in the process of medical education, so as to improve and promote the development of medical education in China to a higher level [11]. In the innovation of teaching methods, foreign scholars have actively explored a variety of new teaching methods. They advocate the student-centered teaching concept and focus on cultivating students ' initiative and creativity. For example, they put forward teaching methods such as case teaching and scenario simulation, so that students can learn and master medical knowledge in practice by simulating real medical scenarios [12, 13]. In addition, foreign scholars have also paid attention to the huge potential for integration between information technology and medical education. Using cutting-edge technologies such as artificial intelligence, big data, and virtual reality to improve medical teaching methods, in order to improve teaching effectiveness and provide a strong basis for personalized teaching [14].

Compared with foreign scholars ' research on the scale and quality improvement of medical education, domestic scholars mostly analyze from the perspective of medical education mode, mainly focusing on the following two aspects: first, the current situation of medical education, examining the interaction between medical education and external environment such as society, economy and culture at the macro level, deeply exploring the ought-to-be logic of the coordination between social needs and the connotative development of medical education [15], and exploring how to adapt to and promote social and economic changes. Especially in the context of the current medical and health system reform, scholars have paid great attention to the positioning and future development direction of medical education. The aim is to construct a medical education development model in line with China 's national conditions [16]. In addition, through the comparative analysis of the similarities and differences of medical education at home and abroad, in order to learn from the experience and lessons, to provide a useful reference for the reform of medical education in China [17]. At the micro level, domestic scholars have paid close attention to the internal mechanism and process of medical education. It focuses on specific aspects such as teaching methods, curriculum setting and practical links, and deeply explores the core elements that affect the quality of medical education. In view of the problems revealed in traditional medical education, we have actively put forward a series of innovative reform proposals to stimulate students ' initiative and innovative spirit by introducing more interactive and heuristic teaching methods. At the same time, the curriculum should be optimized, and the close combination of basic medicine and clinical medicine should be strengthened to cultivate students ' comprehensive quality and innovation ability [18]. The second is the reform of medical education. At the theoretical level, the reform is committed to updating educational concepts and innovating educational models to adapt to the ever-changing medical environment. Modern medical education emphasizes student-centered and focuses on cultivating students ' clinical thinking ability and practical ability. Educators need to constantly update educational concepts, change from teacher-centered to student-centered, and emphasize students ' subjectivity and participation. At the same time, the innovation of education mode is also very important. By introducing modern teaching methods such as blended teaching and online courses, the teaching effect and learning experience can be improved. At the practical level, medical education reform focuses on the combination of clinical practice teaching and community service. Clinical practice teaching is an indispensable part of medical education. Students need to practice in a real clinical environment to improve clinical skills and coping ability [19]. In addition, medical education also encourages students to participate in community services and provides medical services for community residents to cultivate their sense of social responsibility

and mission. This practice-oriented teaching method helps to improve students ' practical ability and teamwork spirit, and lays a solid foundation for future medical work [20].

The academic circles have rich discussions on the allocation of health resources, mainly including the measurement of its fairness and accessibility, the construction of the index system, and the in-depth exploration of the influencing factors. At the level of research methods, it mainly involves the evaluation of fairness and accessibility. Using multivariate statistical analysis, geographic information system and other diversified tools, combined with economic methods such as Gini coefficient and Theil index, it analyzes in detail the distribution differences of health resources among different regions and different groups, and how these differences affect the convenience of residents ' access to medical services [21–24]. When constructing the index system, scholars not only consider the quantity of resources, but also pay attention to the improvement of the quality and efficiency of resources. They not only use the traditional quantitative indicators of health resource allocation, such as the number of health technicians per thousand population and the number of beds, but also introduce a series of indicators to measure service quality, such as medical service efficiency and patient satisfaction, so as to evaluate the effect of health resource allocation more comprehensively and scientifically and provide a more solid basis for relevant policy formulation [25, 26]. In terms of exploring the influencing factors, the academic community has also conducted extensive and in-depth research, including factors such as economic development level, population structure and government policies, which have a profound impact on the allocation of health resources [27, 28]. Generally, regions with higher levels of economic development have stronger economic strength and can invest more funds in the construction and development of health resources. At the same time, the change of population structure will also have an important impact on the allocation of health resources. For example, with the increasing trend of population aging, the demand for medical services is also increasing, which puts forward higher requirements for the allocation of health resources. Government policy is a key means of regulation, which can influence and guide the allocation of health resources by adjusting capital investment and optimizing the structure of resource allocation, so as to meet the different needs of society.

Based on the existing achievements, medical education has undoubtedly accumulated human capital stock for the development of medical and health undertakings, and also provided intellectual resources for the optimization of health resource allocation, thus providing favorable support for the health needs of the Chinese population. In previous studies, domestic and foreign scholars ' research on the two independent fields of medical education and health resource allocation is relatively mature, but there are still some shortcomings: in terms of research depth, most of the research on medical education and health resource allocation focuses on independent research in two different fields, and less can be included in the same framework to discuss the coupling and coordination relationship between medical education and health resource allocation. In terms of time span and research objects, many existing studies are mainly carried out from regions or single provinces and urban agglomerations, and there is a lack of research on the dynamic evolution and change trend of the spatial and temporal pattern across the country and across ten years. In terms of research methods, the existing related research is more qualitative research from an independent perspective. Even if the empirical analysis method is used, it is mostly the description of the current situation of Niki coefficient, Theil index, DEA-Malmquist and so on. It is less involved in the heterogeneity analysis of the coupling and coordination level between the two. The research method of quantile regression has not been used to accurately explore the key factors affecting the relationship between the two and its heterogeneity research.

In view of this, in order to identify the spatial and temporal pattern and heterogeneity of the coupling and coordination between medical education and health resource allocation level, the specific research design of this study is as follows: Firstly, a coupling coordination degree model is constructed to measure the coupling coordination degree of medical education and health resource allocation level in each year. Secondly, according to the coupling coordination degree reflected, the spatial and temporal variation characteristics between regions are investigated by spatial autocorrelation model, kernel density estimation and decomposition. Finally, the quantile regression model is constructed to analyze the influencing factors of society, economy and population from the perspective of coupling coordination level difference, and to reveal the key influencing factors under different quantile coupling coordination levels.

Evaluation of coupling coordination degree between medical education and health resource allocation

Construction of index system

In order to fully reflect the coordination relationship between medical education and health resource allocation, the medical education system is divided into two criteria layers: talent training and social service based on the previous research and the research of Wang Ji

et al. [29, 30]. The existing medical education evaluation system is improved and updated, and six index layers including the number of students in school and medical research institutions are selected.Based on the research of Zhang Jinqiu et al. [31, 32], the allocation of health resources is divided into three subsystems: human resources, material resources and financial resources. The human resource criterion layer includes two representative indicators: the number of health technicians per thousand population and the average number of visits by residents. The material criterion layer includes two representative indicators: the proportion of tertiary hospitals and the density of medical institutions; the financial criterion layer includes two representative indicators: the proportion of total health expenditure in GDP and per capita total health expenditure (Table 1).

Data sources

This study mainly takes 31 provinces in China from 2011 to 2021 as samples to measure the comprehensive development level and coupling coordination relationship of medical education and health resource allocation. The comprehensive evaluation system data are selected from the ' China Statistical Yearbook ' ' China Health Statistics Yearbook ' ' China Health and Family Planning Statistics Yearbook ' ' China Health Statistics Yearbook ' ' China Education Statistics Yearbook ' over the years. According to the division criteria of the National Health Commission, 31 provinces in China are divided into three regions: eastern, central and western regions [33].

Research methods

Entropy method

When medical education and health resource allocation are coupled, the entropy method is used to determine the weight of each index layer, and the final comprehensive evaluation results are obtained according to the calculation results of each index [34]. Through the results to evaluate and analyze the comprehensive development degree of medical education and health resource allocation in various regions, the formula for calculating the comprehensive development level by entropy method is:

$$\mathbf{s_{ij}} = \mathbf{x_{ij}} / \sum_{\mathbf{i=1}}^{\mathbf{n}} \mathbf{x_{ij}} \tag{1}$$

$$\mathbf{e_j} = -1/\mathbf{ln(n)} \sum_{\mathbf{i=1}}^{\mathbf{n}} \mathbf{s_{ij} ln s_{ij}} \tag{2}$$

$$\mathbf{g_j} = 1 - \mathbf{e_j} \tag{3}$$

$$\mathbf{W_j} = \mathbf{g_j} / \sum_{\mathbf{j=1}}^{\mathbf{p}} \mathbf{g_j} \tag{4}$$

$$\mathbf{M_i} = \sum_{\mathbf{j=1}}^{\mathbf{p}} \mathbf{W_j x_{ij}} \tag{5}$$

S_{ij} represents the proportion or contribution of the j th index of the i th year studied, Xij represents the j th index value of the i th region, e_j represents the entropy value of the j th index, g_j represents the information entropy redundancy, W_j represents the weight of the j th index, and M_i represents the comprehensive score of the i th year studied.

Coupling coordination degree model

The coupling coordination degree model can better evaluate and analyze the coordinated development between two or more systems, and the model calculation is simpler and the results are more intuitive. Therefore, this study uses the coupling coordination degree model to

Table 1 Coupled comprehensive evaluation system of medical education and health resource allocation

System	Criterion layer	Index level	weight
Medical education	Personnel training	Number of students enrolled	0.119
		Proportion of medical graduates	0.048
		Number of students enrolled in medical colleges and universities per 10,000	0.046
	Social service	Medical research institution	0.101
		Medical on-the-job training institution	0.185
		Number of health education trainings	0.217
Health resources	manpower	Number of health technicians per 1,000 population	0.032
		Ratio of care to care	0.017
	Material resources	Number of health care institutions	0.033
		Number of bed	0.082
	Financial resources	Total health expenditure as a share of GDP	0.052
		Total health expenditure per capita	0.068

explain the interaction between the two subsystems of medical education and health resource allocation. Based on this, the overall coupling coordination degree of the system is further measured [35, 36], and the calculation formula of the coupling coordination degree is as follows:

$$C = \left[\frac{U_1 U_2}{\left[\frac{U_1 + U_2}{2} \right]^2} \right]^{\frac{1}{2}} \tag{6}$$

$$D = \sqrt{C \cdot N} \tag{7}$$

$$N = \alpha U_1 + \beta U_2 \tag{8}$$

D represents the degree of coupling coordination, and the value range is [0, 1]. *C* is the degree of coupling, and the value range is [0, 1]. The larger the value is, the greater the degree of correlation between medical education and health resource allocation is. *U1* and *U2* are the comprehensive evaluation indexes of the two systems of medical education and health resource allocation respectively. *N* is the comprehensive evaluation index of the two systems as a whole, and α and β represent the contribution coefficients of the two systems respectively.

Spatial auto-regression model

Spatial auto-correlation analysis is one of the statistical test methods. It can measure the auto-correlation of the distribution of spatial things. It is divided into global and local tests. The correlation represents whether the space has agglomeration characteristics [37, 38]. The spatial auto-correlation calculation formula is:

$$\text{Moran's I} = \frac{\sum_{i=1}^{n} \sum_{j=1}^{n} W_{ij} (y_i - \bar{y}) \left(y_j - \bar{y} \right)}{S^2 \sum_{i=1}^{n} \sum_{j=1}^{n} W_{ij}} \tag{9}$$

y_i represents the composite index of the i th province, n represents the number of provincial units, S^2 represents the sample variance, and W_{ij} represents the spatial weight.

Kernel density estimation

In order to effectively investigate the dynamic evolution trend of the coupling coordination level distribution of medical education and health resource allocation, the kernel density curve is used to describe the distribution pattern of the coupling coordination level of the two systems and estimate the probability density [39]. Assuming that f (x) is the density function of random variable x, the formula of probability density estimation is:

$$f(x) = \frac{1}{N_h} \sum_{i=1}^{N} K\left(\frac{X_i - x}{h} \right) \tag{10}$$

Where N is the number of observations, X_i is the independent distribution of observations, x is the mean value, K is the kernel density function, and h is the broadband.

QR quantile regression

QR quantile regression can be used to explore the relationship between the conditional distribution of dependent variables at different quantiles and independent variables. Compared with the traditional least squares method (OLS), it can not only provide the relationship between the conditional mean of the dependent variable and the independent variable, but also describe the characteristics of the conditional distribution of the dependent variable at different quantiles. This feature makes QR quantile regression more flexible and robust in dealing with problems such as heterogeneity, asymmetry, and outliers [40, 41]. In this study, 0.1–0.9 quantiles were selected to analyze the impact of each variable on the coupling and coordination of medical education and health resource allocation in China. The calculation formula is:

$$Q_{yi}\left({}^{\delta}/_{X_i} \right) = X_i' + \beta(\delta) + \varepsilon(\delta) \tag{11}$$

Qyi (δ / Xi) represents the quantile of the δ th condition of y_i, and *β (δ)* represents the estimation of the δ th quantile coefficient.

Evaluation of coupling coordination degree between medical education and health resource allocation

The coupling coordination degree model can provide a systematic perspective, which regards medical education and health resource allocation as two interrelated and interactive subsystems. It can not only describe the static relationship between medical education and health resource allocation, but also reveal the dynamic evolution process between them. Through the analysis of time series data, we can observe how the degree of coordination between the two changes over time, and then explore the influencing factors and mechanisms behind this change.

Time series characteristics

From the temporal level, the coupling coordination degree of the two systems in each province shows a slow upward trend from 2011 to 2021, which is similar to the national average trend, as shown in Fig. 1. In general, the annual average value of the coupling coordination degree between medical education and health resource

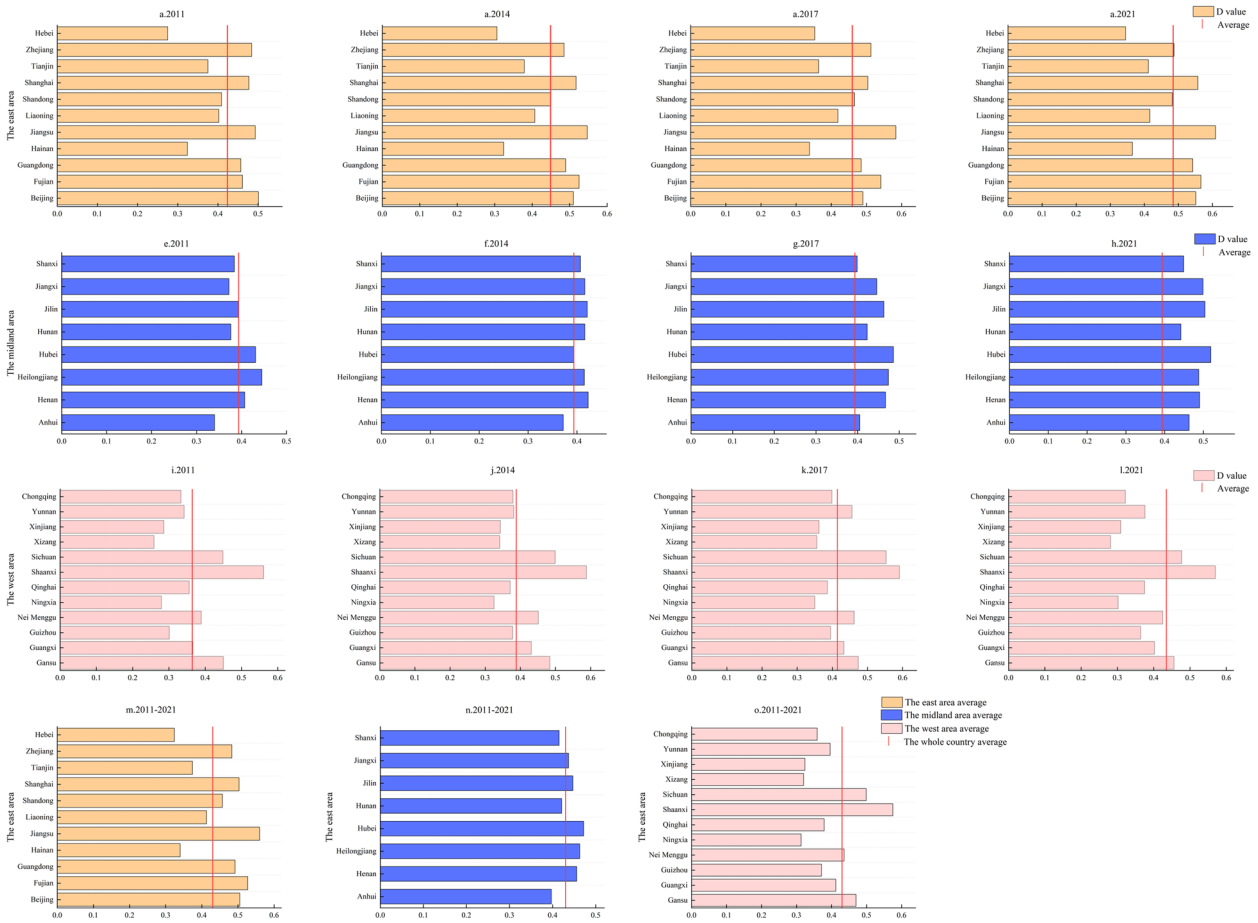

Fig. 1 Trend of coupling coordination degree between medical education and health resource allocation in China from 2011 to 2021

allocation in China is 0.430, and there are 16 provinces that exceed the average value. Among them, 7 provinces in the eastern region, such as Beijing, Shanghai and Guangdong, exceed the average value, and 5 provinces in the central region, such as Henan, Heilongjiang and Hubei, exceed the average value, while only 4 provinces in the western region, such as Gansu, Inner Mongolia, Sichuan and Shaanxi, exceed the average value. The coupling coordination degree of the two systems in each province shows a good development trend, but in terms of index size, most provinces are generally far from the ideal state.

From the regional level, taking the end of the observation period in 2021 as an example, the top three provinces in the eastern region are Jiangsu (0.609), Fujian (0.566) and Shanghai (0.557). The top three provinces in the central region are Hubei (0.519), Jilin (0.504), Jiangxi (0.499) and Shanxi (0.499). The top three provinces in the western region are Shaanxi (0.591), Sichuan (0.553), and Inner Mongolia (0.462). During the observation period, the top five provinces in the growth rate are Tibet (37.66%), Anhui (36.26%), Jiangxi (33.93%), Yunnan (33.59%), and Guizhou (31.12%). The top five provinces are Zhejiang (0.63%), Liaoning (3.36%), Gansu (5.28%), Shaanxi (5.35%) and Qinghai (8.28%). The western region is gradually catching up with the eastern and central regions, and the regional gap is shrinking.

Different space levels

The spatial autocorrelation model can reveal the internal relationship and interaction mechanism of the coupling coordination degree of medical education and health resource allocation in spatial layout. By quantifying the spatial autocorrelation coefficient (Moran 's I), it reveals the mutual influence and dependence between adjacent areas, and deeply analyzes the distribution pattern of the coupling coordination degree of the two systems in geospatial space. It is further helpful to identify high-value agglomeration areas and low-value agglomeration areas, so as to reveal the spatial heterogeneity of the coupling coordination degree of the two systems between regions. In addition, the spatial autocorrelation model also

provides a scientific basis for optimizing the allocation of medical education resources and health resources, and promotes the balanced development of the two systems between regions.

Global spatial auto-correlation analysis

Based on the results data in Fig. 1, the global auto-correlation analysis of the coupling and coordination level of medical education and health resource allocation in China is carried out. The results are shown in Table 2. From 2011 to 2021, the global spatial auto-correlation *P* value of the coupling coordination degree of the two systems was less than 0.05, which passed the significance test, and the Moran index was positive, indicating that there was a significant spatial positive correlation between the coupling coordination level of medical education and health resource allocation in China. The spatial agglomeration gradually increased, and the spatial distribution had rules to follow, that is, the provinces and cities with higher coupling coordination level were adjacent to each other, the provinces and cities with lower coupling coordination level were adjacent to each other, the similarity between adjacent provinces and cities was high, and the regional development was uneven. However, in general, the Moran index showed a slight upward trend from 2011 to 2021.

Local spatial auto-correlation analysis

In order to investigate the spatial distribution of the coupling of medical education and health resource allocation in China, the local spatial autocorrelation is used to measure the spatial agglomeration level of the coupling coordination degree of the two systems, as shown in Table 3. The results show that the global Moran index of the coupling of medical education and health resource allocation in China in 2011 is 0.048 ($p=0.011$), indicating that there is a positive spatial auto-correlation relationship between medical education and health resource allocation at a significant level of 5%, that is, there is spatial dependence. Some provinces are spatially concentrated. From the perspective of spatial distribution, there are 6 and 8 provinces in the first and third quadrants, respectively, showing high-high agglomeration and low-low agglomeration. There are 12 and 5 provinces in the second and fourth quadrants, respectively, showing high-low agglomeration and low–high agglomeration.In 2021, the global Moran index of the coupling of medical education and health resource allocation in China is 0.051 ($p=0.011$), indicating that there is a positive spatial auto-correlation relationship between medical education and health resource allocation at a significant level of 5%. From the perspective of spatial distribution, there are 7 and 15 provinces in the first and third quadrants,

Table 2 Global Moran index variation of the coupling coordination between the two systems from 2011 to 2021

year	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
I value	0.048	0.038	0.041	0.061	0.061	0.073	0.044	0.067	0.067	0.062	0.051
P value	0.011	0.015	0.012	0.006	0.006	0.006	0.016	0.007	0.006	0.005	0.011

Table 3 Spatial distribution pattern of local Moran index for the coupling coordination between the two systems in 2011–2021

Year	District	HH region	LH region	LL region	HL region
2011	The east area	Jiangsu, Zhejiang, Fujian, Guangdong, and Shanghai	Shandong, Tianjin, Hebei, Hainan, Liaoning		Beijing
	The midland area	Hubei	Heilongjiang, Jilin, Anhui, Jiangxi, Hunan	Shanxi	Henan
	The west area		Yunnan, Guangxi	Nei menggu, Xinjiang, Ningxia, Qinghai, Xizang, Guizhou, Chongqing	Gansu, Shaanxi, and Sichuan
2021	The east area	Jiangsu, Zhejiang, Fujian, Guangdong, and Shanghai	Shandong, Tianjin, and Hebei	Hainan, Liaoning	Beijing
	The midland area	Hubei, Jiangxi	Anhui, Hunan	Heilongjiang, Jilin and Shanxi	Henan
	The west area			Nei menggu, Xinjiang, Ningxia, Qinghai, Xizang, Guizhou, Chongqing, Gansu, Yunnan, Guangxi	Shaanxi, Sichuan

respectively, showing high-high agglomeration and low-low agglomeration. There are 5 and 4 provinces in the second and fourth quadrants, respectively, showing high-low agglomeration and low–high agglomeration. From the perspective of transition, 25.81% of the provinces have transitions, among which Jiangxi has transitioned from low–high agglomeration to high-high agglomeration, Heilongjiang, Jilin, Yunnan and other six provinces have negative transition from low–high agglomeration to low-low agglomeration, and Gansu has negative transition from high-low agglomeration to low-low agglomeration.

Kernel density estimation analysis

The kernel density function, with its non-parametric characteristics, intuitive visualization ability and sensitivity to local analysis, can intuitively observe the spatial distribution pattern and relative intensity of the coupling coordination degree of medical education and health resource allocation with the help of kernel density map, and then evaluate the coupling coordination of the two systems, so as to more comprehensively understand the distribution characteristics and interrelationships of medical education and health resource allocation in different regions. In order to better show the temporal and spatial evolution of the coupling coordination degree of medical education and health resource allocation in 31 provinces of China, this paper uses the kernel density estimation method to analyze the evolution characteristics and differences of the coordination degree between the two systems. The kernel density results of the coupling coordination degree of the two systems are shown in Fig. 2 and Table 4.

It can be seen from Fig. 2 (a) that the dynamic evolution of the coupling and coordination degree of medical education and health resource allocation has the following characteristics through the distribution characteristics of the curve: in 2011, the kernel density curve moved first left and then right, indicating that the coupling and coordination degree of medical education and health resource allocation increased significantly nationwide. From the perspective of curve distribution, the height of the main peak shows a trend of increasing first and then decreasing, and the width shows a trend of narrowing first and then widening, indicating that the coupling coordination degree shows a trend of narrowing first and then expanding. From the perspective of curve extensibility, the kernel density curve of each year shows a clear right-tailed widening phenomenon, indicating that the gap in coupling coordination between the two is gradually expanding from 2011 to 2021. From the perspective of the number of curve peaks, the change trend during the observation period is ' single peak-double peak-single peak ', indicating that the polarization degree of the coupling and coordination degree of medical education and health resource allocation in China is weakened and gradually develops towards equalization.

In order to further analyze the dynamic evolution of the coupling coordination degree of medical education and health resource allocation in the eastern, central and western regions, this paper describes the nuclear density results of the coupling coordination level of the two systems from 2011 to 2021, as shown in Fig. 2 (b-d). From the perspective of distribution location, the center of the curve in the central region shows an evolution process of moving right year by year, and the eastern and western regions show a trend of moving left first and then moving right. From the perspective of distribution pattern, there are obvious differences in the three regions. The peak value of the eastern and central regions shows a downward trend in the fluctuation, and the trend of the peak width is ' narrowing-widening ', while the peak fluctuation of the western region shows an upward trend, and the width becomes narrower, which indicates that the coupling and coordination degree of medical education and health resource allocation in the eastern and central regions has been down-regulated, while the coupling degree of the two in the western region has been significantly up-regulated.From the perspective of curve ductility, the kernel density curves of the eastern and central regions showed a right-tailed widening trend during the investigation period, indicating that the gap between the coupling coordination degree of the two systems in each region increased. The nuclear density curve in the western region shows a left tail, and the tail is getting shorter and shorter, which indicates that the gap between the coupling coordination degree of the two systems in each region is narrowing. From the number of curve peaks, during the investigation period, except that the western region has always been stable as a single peak, it shows that the western region is currently in a state of graded weakening; the eastern and central regions showed a trend of ' single peak-double peak-single peak ', indicating that it showed a polarization state in the early stage, and then the degree of polarization gradually weakened, and the gap within the region gradually decreased.

QR quantile regression analysis

Quantile Regression (QR) can reveal the influence of independent variables on dependent variables at different quantiles, so as to understand the relationship between variables more comprehensively. When dealing with the spatial and temporal heterogeneity of variables, compared with the traditional OLS model, the QR model can better capture the complexity of the data, reduce the problems caused by outliers and non-normal

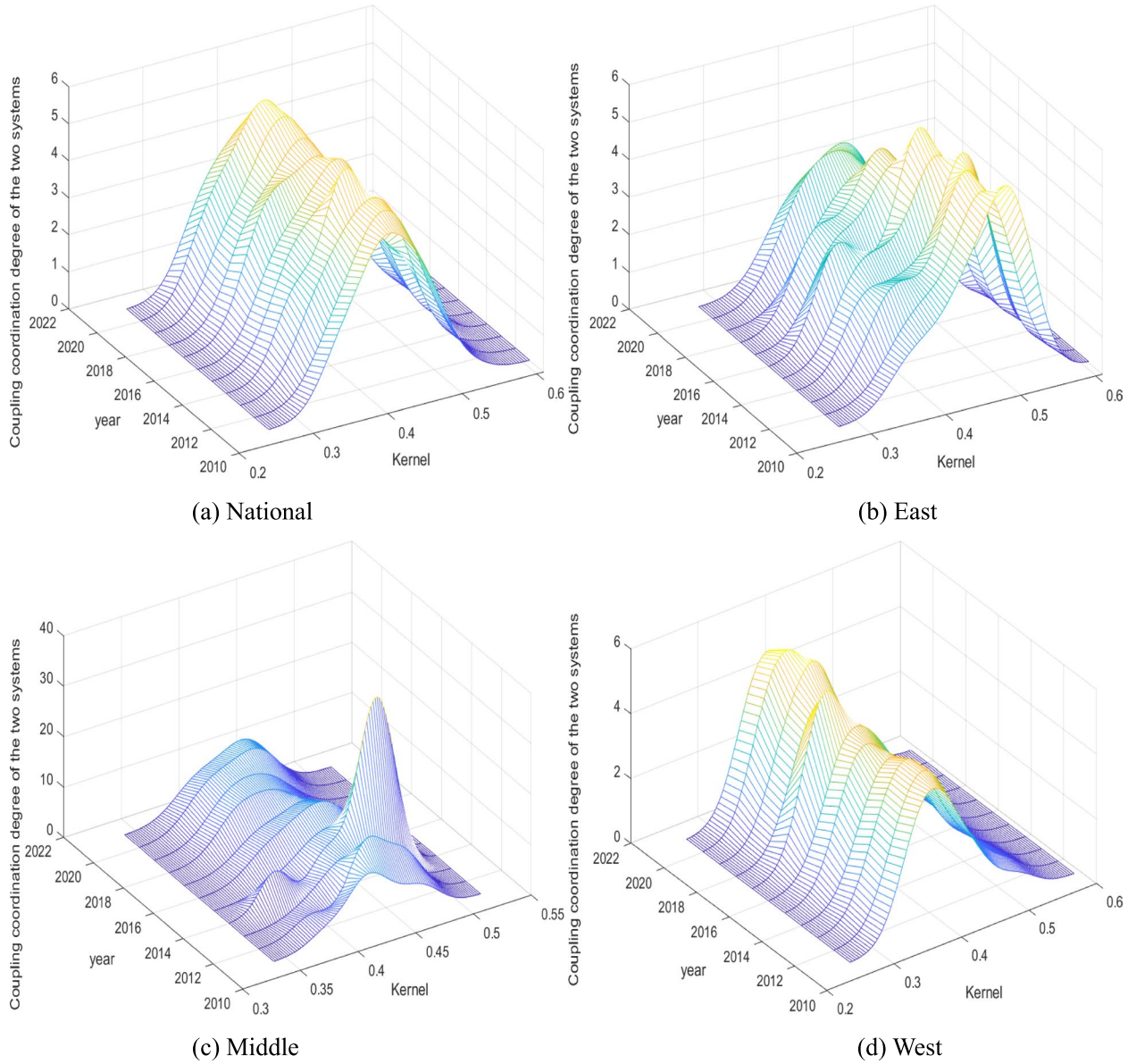

Fig. 2 Distribution evolution of coupled coordination degree between two systems

Table 4 Distribution characteristics of kernel density curves of coupling coordination of medical education and health resource allocation in China and the three major regions

District	The number of crest changes	Main peak displacement	Main peak change	Ductility	Polarization characteristics
The whole country	Unimodal-Bimodal-Unimodal	Move left-Move right	rise-fall narrower-wider	Right trailing widens	Polarization-Less polarization
The east area	Unimodal-Bimodal-Unimodal	Move right-Move left	rise-fall narrower-wider	Right trailing widens	Polarization-Less polarization
The midland area	Unimodal-Bimodal-Unimodal	Move right	rise-fall narrower-wider	Right trailing widens	Polarization-Less polarization
The west area	Unimodal-Unimodal	Move right-Move left	fall-rise wider-narrower	Left trailing convergence	Differentiation weakening

Table 5 Regression analysis of quantile results of influencing factors

System	Index	10%	20%	30%	40%	50%	60%	70%	80%	90%
Economic development level	Per capita GDP	3.812*** (3.91)	3.359*** (10.63)	2.923*** (6.95)	2.666*** (6.25)	3.044*** (4.71)	3.428***(4.85)	4.584*** (5.51)	5.723*** (7.02)	7.931*** (8.79)
	Differences in residents' income	0.025 (1.54)	0.047*** (3.44)	0.046** (2.43)	0.071*** (4.10)	0.070*** (4.20)	0.067***(4.11)	0.054*** (3.76)	0.049** (2.92)	0.033* (1.92)
Population development level	Population size	0.019 (1.55)	0.028*** (3.69)	0.022** (3.15)	0.025*** (3.54)	0.022** (2.54)	0.023**(2.66)	0.015* (1.81)	0.017** (2.41)	0.037** (3.05)
Social development level	the level of R & D innovation	0.001 (0.08)	-0.001 (-0.66)	-0.004** (-2.16)	-0.005*** (-4.31)	-0.004** (-3.13)	-0.001 (-0.71)	0.001 (0.11)	0.001 (0.32)	-.001 (-0.06)
	The degree of aging	-0.002 (-0.54)	-0.002 (-1.04)	-0.001 (-0.28)	0.001 (0.10)	0.001 (0.31)	0.003 (1.03)	0.004 (1.74)	0.002 (1.01)	-0.004 (-1.26)

***, **, *represents the significance level of 1 %, 5 %, 10 % respectively

distribution, so as to avoid the deviation that may be caused in statistical analysis. By setting different quantiles, the QR model weights the samples according to these quantiles, so as to estimate the conditional distribution of dependent variables under different conditions, and then reveal the marginal effect of the coupling coordination degree between medical education and health resource allocation. The advantage of this method is that it not only avoids sample reduction, but also considers the information of the entire sample set, thus providing a more robust analysis framework to supplement the limitations of the OLS model. Therefore, this paper introduces the QR quantile regression model to further analyze the influence of each variable at different quantiles on the coupling coordination degree of medical education and health resource allocation, as shown in Table 5.

Based on the analysis of quantile regression model, per capita GDP, residents ' income difference and population size all have a significant positive impact on the coupling coordination level of the two systems. Specifically, the β coefficient of per capita GDP at each quantile fluctuates between 2.666 and 7.931, and basically shows a V-shaped trend. Among them, the 0.1–0.4 quantiles basically show a gradual weakening trend, and the 0.5–0.9 quantiles show a gradual upward trend, and all passed the significance test at the 1% level. It shows that the level of economic development has a positive effect on the degree of coupling and coordination between the two systems, and the higher the level of economic development, the higher the degree of coupling and coordination between the two systems. The income difference of residents in the 0.2–0.9 quantile has a positive impact on the coupling coordination degree of the two systems. Specifically, the 0.2–0.5 quantile basically shows a gradual upward trend, and the 0.6–0.9 quantile shows a gradual downward trend. The variation range of the β coefficient is between 0.033 and 0.071, and all passed the significance test of the 5% level. This shows that the income difference of residents has a positive effect on the coupling coordination degree of the two systems, but this effect is not nonlinearly increasing, but gradually decreases with the expansion of the income gap.The population size has a significant positive impact on the coupling coordination degree of the two systems, and its β coefficient fluctuates between 0.015 and 0.037, and both pass the significance test at the 5% level, indicating that with the increase of population size, the coupling coordination degree between the two systems will also increase accordingly. However, the level of R & D innovation has a significant negative impact on the coupling coordination level of the two systems only at the 0.3–0.5 quantile, and its β coefficient is between-0.005 and 0.004, and both pass the significance test of the 5% level, which indicates that at the low quantile level, with the improvement of the level of R & D innovation, the coupling coordination level between the two systems has declined. The degree of aging has not passed the significance test for the coupling coordination level of the two systems at each quantile, so it cannot be said that there is a significant correlation between the degree of aging and the coupling coordination level of the two systems.

Robustness test

In order to ensure the stability and reliability of the results obtained, this paper conducts a lag-phase robustness test on the explanatory variable, that is, the coupling coordination level of the two systems. Model (1) is the benchmark regression result, and Model (2) is the one-period lag two-system coupling coordination level lag one-period regression result. The results of the test show that the positive and negative of the main explanatory variables and the overall significance have not changed significantly, which further confirms the robustness of the benchmark regression results. The results are shown in Table 6.

Discussions

The coupling coordination degree of medical education and health resource allocation in China shows a steady upward trend. Although the growth rate is relatively flat, the coupling coordination degree of each province has been improved to a certain extent. With the improvement of the quality of medical education and the optimization of health resource allocation, the interaction and synergy between the two systems have been enhanced as a whole. With the continuous growth of China 's economy and the overall progress of society, the government 's investment in medical and health undertakings has increased year by year, which provides a solid material basis for the development of medical education. The education department has significantly improved the quality of medical education by reforming the medical education system, strengthening the construction of teaching staff, and updating teaching equipment and teaching materials. At the same time, with the improvement of residents ' health awareness, the demand for high-quality medical services is increasing, which forces medical education to adapt to the market demand and cultivate more medical talents with clinical practice ability [42]. Comparing the coupling coordination degree between regions, the gap between East-Central and East–West is gradually narrowing, while there are still significant differences between Central-West. With the advancement of economic integration in the eastern and central regions, the effective diffusion of education and health resources to the central region has been promoted, and the rapid rise of the central region has been accelerated. At the same

Table 6 Robustness test results

System	Index	(1)	(2)
	Din		0.391*** (0.057)
Economic development level	Per capita GDP	2.254***(0.540)	1.797***(0.556)
	Differences in residents' income	0.057***(0.008)	0.029*** (0.008)
Population development level	Population size	0.001(0.002)	0.002 (0.002)
Social development level	the level of R & D innovation	-0.001(0.001)	-0.001(0.001)
	The degree of aging	-0.001(0.001)	-0.001(0.001)

*** represents the significance level of 1 %

time, the cooperation and fixed-point assistance in medical education and health resources between the eastern and western regions continued to deepen, and the medical education and health resources in the western region were improved, which promoted the construction of a diversified medical system with medical and health care as the core and medical education as the support, and gradually improved the medical security system. Relying on the advantages of economic development, the eastern region has gathered high-quality medical education resources, attracted high-tech talents, and formed a strong atmosphere of medical education. High population density and high-quality living needs have created an urgent need for high-quality medical services, and promoted the concentration and optimal allocation of medical resources in the region. Due to the remote location and inconvenient transportation in the western region, the development of medical education and the flow of medical resources are limited, and the number and quality of medical colleges are limited, which leads to the lack of medical education resources and affects the training and reserve of local medical talents.As a transitional zone between the eastern and western regions, the central region enjoys the economic radiation effect of the eastern region and faces the development needs of the western region, which has unique geographical advantages. With the steady economic growth and population growth in the central region, the demand for medical services has grown steadily, providing lasting impetus for medical education and health resource allocation. Through national policy support to promote the development of medical and health care in the central region, narrow the gap with the eastern and western regions, and promote the balanced distribution and optimal allocation of medical and health resources in the country.

From 2011 to 2021, the spatial distribution characteristics of medical education and health resource allocation in China showed significant spatial correlation and cluster effect. The global Moran 's I index has been positive for many years. The stability of this statistical index reflects that the spatial distribution of medical education resources and health resource allocation across the country is not random, but shows a certain regularity, that is, the geographically close regions have similar trends in the development level of these two aspects. The spatial distribution of medical education and health resources allocation showed a clear change from east to west. Due to the high level of economic development, population density and policy support, the provinces in the eastern region have relatively more investment and accumulation in medical education and health resource allocation, attracting a large number of medical and health high-tech talents, forming a ' high-high ' agglomeration model. At the same time, due to the remote geographical location, poor natural conditions, lagging economic development and brain drain, the provinces in the western region have relatively less investment and accumulation in medical education and health resource allocation, and the level of medical services is relatively low, forming a ' low-low ' agglomeration model.From 2011 to 2021, the Chinese government has implemented a series of policies and measures aimed at optimizing the allocation of resources and narrowing the regional development gap, such as the western development, the revitalization of the northeast, the rise of the central region and other strategies, as well as poverty alleviation work in poverty-stricken counties and medical and health support policies for rural areas. The implementation effect of these policies is reflected in the spatial distribution of medical education and health resource allocation. For example, the local Moran 's I index rose from 0.048 in 2011 to 0.051 in 2021.Although the change range is not large, it shows that the imbalance of resource allocation has improved, and resources have begun to flow to the central and western regions, but the overall gap between the eastern and central and western regions is still significant. In addition, with the passage of time, some provinces located in the second and fourth quadrants have gradually transitioned to the first and third quadrants, which reflects that the spatial distribution of medical education and health resource allocation in China is undergoing a process from equilibrium to imbalance, and then to a new equilibrium adjustment. This change is not only guided by national policies, but also affected by

multiple factors such as market forces, population mobility and social needs.

The Kernel density estimation analysis reveals the dynamic characteristics of the coupling coordination level of medical education and health resource allocation in different geographical regions over time. In the whole country and the eastern region, the coupling and coordination degree of medical education and health resource allocation tends to be concentrated after experiencing initial fluctuations, and the polarization phenomenon has weakened. This change trend may be related to the country 's key development policy for the eastern region. As an economically developed region, the eastern region has given priority to the development of infrastructure construction and public service system, and various undertakings, including medical education and health resource allocation, have also been significantly strengthened. With the passage of time, the medical education and health resource allocation in this area have gradually achieved more efficient integration and utilization, thus improving the level of coupling and coordination. The change trend of coupling coordination degree in the central region is similar to that in the whole country and the eastern region, but because of its low starting point, the coupling coordination degree is obviously improved. This indicates that the central region may have taken a series of measures to strengthen the allocation of medical education and health resources in recent years, such as improving the level of medical education, optimizing the allocation of medical education and health resources, and improving medical and health infrastructure.The distribution of coupling coordination degree in the western region is relatively stable, but the shift of peak position and the weakening of polarization may reflect the special development trend and regional differences in medical education and health resource allocation in the region. As an economically underdeveloped area, the infrastructure construction and public service system in the western region started late. However, in recent years, the state 's support for the western development strategy has been increasing, which may lead to the investment and development of medical education and health resource allocation in the region. However, due to factors such as economic development and natural conditions, the development of the western region still faces many challenges, which may lead to the improvement of its coupling coordination degree is not as obvious as that of the eastern and central regions.The main peak displacement in the whole country and the eastern region shows that the coupling and coordination degree of medical education and health resource allocation has improved over time. These regions have made some progress in integrating medical education and health resources. However, the transfer of the main peak position and the weakening of the polarization degree may also mean that although the overall improvement has been made, in some sub-regions or specific time periods, there may be resource reallocation, resulting in fluctuations in the degree of coupling and coordination. This suggests that while promoting overall development, policymakers should also pay attention to balanced development within the region, avoid excessive concentration or neglect of resources, and ensure that all regions can share development results fairly.

The RQ quantile regression analysis shows that the impact of per capita GDP on the medical and health field is a dynamic and non-linear process. When the per capita GDP is low, although the financial resources are limited, the optimal allocation of medical resources can be realized through scientific planning, effective management and innovative financing mode, so as to strengthen the primary medical service system, improve the accessibility of medical services, and provide basic guarantee for public health [43]. With the growth of per capita GDP, the increase of fiscal revenue enables the government to increase investment in medical education and health resource allocation, so as to promote the quality and efficiency of medical services, improve the imbalance of resource allocation [44], and provide support for the sustainable development of the economy. The positive incentive effect of residents ' income difference on the coupling and coordination of the two systems at the middle and high quantiles is gradually weakened, indicating that moderate income difference can stimulate social vitality and creativity, and then provide more impetus and resource support for medical education and health resource allocation.When the income difference of residents exceeds the threshold, its positive incentive effect on the coupling and coordination level of medical education and health resources tends to weaken. Low-income groups may be difficult to obtain necessary medical services due to limited resources, which directly affects their health level. The inequality of income difference may further aggravate the differentiation of the labor market, limit the employment opportunities and career development of low-income groups, and thus pose a threat to the stability and growth of the entire economic system. The population size has a significant positive impact on it in the middle and high quantiles. The expansion of population size leads to a significant increase in the demand for medical services, especially in densely populated areas. This trend has prompted the government and educational institutions to increase investment in medical education, and optimize the allocation of health resources. By optimizing medical personnel training, facility construction and improving the public health system, strengthening medical security system and scientific and technological

innovation, promoting cross-regional cooperation, and paying attention to health education and public health emergency preparedness [45], in order to meet the health needs of the people, so as to better promote the sustained and healthy development of China 's medical and health undertakings.The level of R & D innovation has a negative impact on it at low quantiles, indicating that the level of R & D innovation has not yet reached a higher stage, and its relatively low development trend may hinder the effective integration and synergy of medical education and health resource elements. Insufficient technological innovation, limited R & D investment, and low conversion rate of innovation results limit the technological progress and application expansion of the two systems, which in turn affects the level of coupling and coordination between the two systems. In terms of resource allocation, due to the lack of advanced technical support and innovation guidance, it may lead to low efficiency of resource allocation and waste of resources, which restricts the improvement of medical education and health service quality [46]. On the one hand, aging may lead to changes in the labor market, changes in consumer demand, etc., which will have a positive impact on the two systems [47]. On the other hand, aging may also bring problems such as social welfare pressure and increased demand for medical care, which have a negative impact on the two systems [48]. The offsetting of these positive and negative effects may lead to the fact that the degree of aging has no significant effect on the improvement of the coupling and coordination level of the two systems.

Advantages and limita-tions

This study also has some limitations. First of all, due to data limitations, this study did not discuss the different educational levels, scales and structures of undergraduate, postgraduate and doctoral students in medical education from 2010 to 2020 on the level of health resource allocation. Secondly, when determining the appropriate scale of medical education, this study mainly focuses on demand-side factors such as resident population, floating population and urban–rural differences, and does not explore supply-side factors such as training conditions of medical colleges and universities. In view of the above shortcomings, it is expected to continue to improve in future research in order to obtain more reliable conclusions and policy recommendations.

Conclusion and policy suggestion

Healthy China needs a high-quality medical education system. Correct understanding of the coupling and coordination degree of medical education and health resource allocation, as well as the influencing factors of distribution dynamics, spatial and temporal evolution and social economy, can provide practical guidance for the construction of a new pattern of medical education development. The study found that the coupling coordination degree of the two systems of medical education and health resource allocation level showed a steady upward trend during the observation period, and the global spatial positive correlation was gradually enhanced. The spatial agglomeration characteristics of ' high-high agglomeration ' and ' low-low agglomeration ' were found locally, and 25.81% of the provinces had transitions in the distribution pattern. The spatial difference of coupling coordination degree shows a narrowing trend and develops towards equalization. Affected by social, economic and demographic factors, per capita GDP, residents ' income difference and population size have a positive effect on the coupling and coordinated development of the two systems. Based on the above research conclusions, the following policy recommendations are proposed.

First of all, we should strengthen the quality monitoring of medical education and improve the contribution of medical education in the allocation of health resources. The results show that the establishment of a supply and demand balance mechanism for medical education and health resource allocation, and the reasonable determination of the scale, structure and distribution of medical education are conducive to promoting the improvement of regional medical and health service capabilities [49, 50]. Although improving the scale of medical education can meet the needs of medical and health services for human capital to a certain extent, it can promote the improvement of the coupling and coordination between medical education and health resource allocation in various regions. However, when the scale effect is lost, the development level of medical education is difficult to support the construction of medical and health service system. Therefore, while moderately expanding the scale of medical education, we should focus on optimizing the quality of education, increase investment in medical education funds, policies and resources at the national level, and decentralize powers to provincial education administrative departments in a step-by-step and phased manner. According to the actual needs of the allocation of health resources in local regions, each province connects the development of medical education with the improvement of the allocation of health resources, and promotes the improvement of regional medical and health standards [51, 52]. Focusing on the national medical center and the national regional medical center, we will build a regional medical education community, narrow the differences in medical education between regions, realize the sharing of medical

resources in the region, strengthen the complementary advantages of cooperation, and realize the high-quality development of medical education.

Secondly, we should give full play to the resource advantages of talent gathering in the ' highland ' of medical education, make better use of the mechanism of influencing factors such as socio-economic population, and promote the coupling and coordination level of the two systems to develop in a high-quality and coordinated manner. Although there are significant spatial differences in the coupling and coordination degree between medical education and health resource allocation, in the face of the structural imbalance of health resource allocation, resource misallocation and low input efficiency, especially the lack of effective supply of high-quality health resources in grass-roots and rural areas, the contradiction between supply and demand of medical and health resources has become increasingly prominent [53]. Therefore, it is necessary to use the positive spatial correlation between the coupling coordination degree of medical education and regional innovation level, build a long-term cooperation and collaborative governance mechanism of regional medical education, and give full play to the spatial radiation effect of high coupling coordination region, which can not only promote the positive diffusion of coupling coordination level, but also promote the coupling coordination degree of medical education and regional health resource allocation to the high-quality coordination level [54]. In the new stage of development, economic development is mainly driven by innovation, and the development of medical and health undertakings also depends on the innovative role of medical education knowledge and technology [55]. Therefore, with the improvement of economic development level, accelerating the promotion of regional R & D level is conducive to laying the economic and technical foundation for medical education. Then, under the influence of population size and aging process, the medical and health industry should actively feedback the talent demand intention to colleges and universities in combination with social reality, promote multi-agent active docking, and form a cultivation mechanism of government, universities and industry coordination [56].

Authors' contributions

Conceptualization: Li Siyuan. Study design: Wu Xiangwei. Data collection: Zhu Yan.Writing manuscript: Chen Jieting, Zhu Yan. Data analysis: Song Zhilong. Preparation of Tables and supplementary material: Zhu Yan. Critical review: Chen Jieting, Zhu Yan, Song Zhilong, Li Siyuan, Wu Xiangwei. All authors have read and approved the manuscript.

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Availability of data and materials

All data are available upon request from the corresponding author Dr. Wu Xiangwei on reasonable request, at wxwshzx@126.com.

Declarations

Ethics approval and consent to participate

This article does not address any ethical issues.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

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