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Three-medical linkage in China: trend evolution and obstacle identification

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Abstract

Background "Three-medical linkage" is a key concern of the healthcare system reform deepening in China, while it has not achieved the expected outcomes yet. The issues of "no-linkage" or "linkage without moving" have increasingly become a major challenge.

Methods Data was obtained from various Yearbooks in China. Coupling coordination degree and gravity models were employed to analyze the spatio-temporal evolution pattern of the "three-medical linkage" in 31 provinces. The combination forecasting method was used to forecast the development trend of the "three-medical linkage." We constructed the obstacle degree model to identify the main obstacles to coordinated development.

Results The overall development of the three systems exhibited a continuous upward trend. The coupling coordination grade of the "three-medical linkage" system has progressed from the disorderly development stage to the transitional stage in most provinces. The Beijing-Tianjin-Hebei and Yangtze River Delta regions are the most closely connected. Regional disparities in the degree of coupling coordination will widen in the future. The number of people benefiting from maternity insurance, per capita total health expenditure, and new drug research and development (R&D) costs hindered the coordinated development of the three systems.

Discussion Highlighting the improvement of the "three-medical linkage" is essential. Under the goals of Healthy China and SDG3 (Good Health and Well-being), further efforts are needed to address systemic barriers and institutional deficiencies. The Chinese government should increase capital input to overcome major obstacles and carefully evaluate the imbalance in regional development.

Keywords Three-medical linkage, Spatial-temporal pattern, Regional disparity, Coupling coordination degree model

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Background

Healthcare service inequity, health investment inefficiency, and disorders in pharmaceutical management are common challenges in various countries [1]. To address these challenges, numerous countries have developed healthcare models tailored to their contexts. For instance, the UK relies on a centralized system emphasizing hierarchical referrals and coordinated care through its National Health Service (NHS), whereas the US operates a highly decentralized, market-oriented model with fragmented management of healthcare services, insurance, and pharmaceuticals [2, 3]. The social health insurance system of

Germany emphasizes collaboration between insurers and healthcare providers, whereas Japan focuses on cost containment and universal access through strict regulatory oversight. However, none of these models explicitly integrate healthcare services, insurance mechanisms, and pharmaceutical supply into a unified reform framework [4, 5].

The Sanming healthcare reform in China is a systematic reform conducted against the backdrop of a new medical reform. In 1978, China initiated market-oriented economic reforms that disrupted the original public medical insurance and healthcare service delivery systems to some extent [6]. The granting of autonomy to hospitals without the corresponding public financial support has led healthcare institutions to become increasingly profit-driven [7]. This resulted in growing disparities in medical services between urban and rural areas as well as across different regions [8–10], widening gaps in healthcare poverty and health outcomes among provinces, declining equity in healthcare access, and reducing efficiency of health investment. The concern of “expensive and difficult access to healthcare” has become increasingly prominent [11]. To address these challenges, the Chinese government has been dedicated to exploring a new path of medical reform tailored to its national characteristics since the beginning of the 21st century. The new medical reform follows a “practice-understanding-practice” model, continuously advancing in depth. During this process, various regions have actively explored reform strategies, resulting in numerous exemplary cases [12]. For instance, Shanghai has expanded its “1 + 1 + 1” family doctor contract model, Yancheng from the Jiangsu Province has introduced personalized medical service packages, and Yiyang from the Henan Province has innovated DRGs management methods. Among the numerous cases, the Sanming healthcare reform has gained the widest recognition and continues to be widely implemented [13, 14]. The core of this reform lies in controlling the excessive growth in hospital expenditure through comprehensive systemic reforms [15]. Studies have validated the effectiveness of the Sanming healthcare reform [13, 15]. Following its success, the National Health Commission issued a notice summarizing the experiences of Sanming City and encouraging provinces nationwide to promote the Sanming model [12].

Reform has always focused on specific areas due to the lack of integration in the Chinese healthcare system and the interference of various vested interests [16–18]. However, in the Sanming healthcare reform, the “integrated reform of medical treatment, medical insurance, and medicines supply (the ‘Three-Medical linkage’)” is the essence of the reform [19]. Focusing on the connotation, the three major systems involved in the reform encompass core components of healthcare system and represent key elements within the broader healthcare framework [20]. Specifically, according to the World Health Organization (WHO), the healthcare system can be divided into six core building blocks: health services, health workforce, health information systems, essential medicines (vaccines, and technologies), health financing, and leadership and governance [21]. The medical services system corresponds to the organization and provision of health services, the medical insurance system aligns with health financing, and the pharmaceutical system responds to essential medicines and products. By focusing on these goals, the Sanming Reform promoted multidimensional changes in the medical field [22]. Public hospital reforms involve the elimination of drug-based supplementary income and implementation of comprehensive reforms in procurement mechanisms, staffing, and regulatory frameworks. To improve the medical insurance system, it seeks to explore the Chinese payment methods, expand coverage, and enhance protection. Pharmaceutical production and distribution further ensure the supply of medicines and establish a strictly centralized bidding and procurement system for medicines and consumables. These measures reduce drug prices and regulate the average medical insurance cost per visit. Overall, the reform implementation can reduce the share of out-of-pocket health expenses [23], promote allocation and utilization of health resources [24], and enhance patient satisfaction [25].

Currently, research on the coordinated development of the medical and health fields mainly focuses on the following aspects: First, the relationship between health and other social systems. Society represents a complex and interdependent system wherein various subsystems, including healthcare, ecology, and economy, exhibit intricate and multifaceted coupling relationships. Some studies have found that healthcare systems are associated with external environments, such as economic [26], natural [27], policy [28], legal [29], public opinion [30], and humanities environments [31, 32], as shown in Fig. 1. Understanding and recognizing the relationship between other social and healthcare systems will help better address healthcare concerns. Second, a relationship exists between the subsystems within the healthcare system. A deep coupling and coordination was observed among the medical treatment, medical insurance, and medicines supply systems, and these systems are closely related and influence each other, as shown in Fig. 1. The pharmaceutical industry affects the profitability of medical service institutions from the perspective of the relationship between medical treatments and the medicines supply. Only when the pharmaceutical industry reaches an advanced level can it significantly promote coordinated development with the medical service industry [33], and, in turn, medical services will determine the

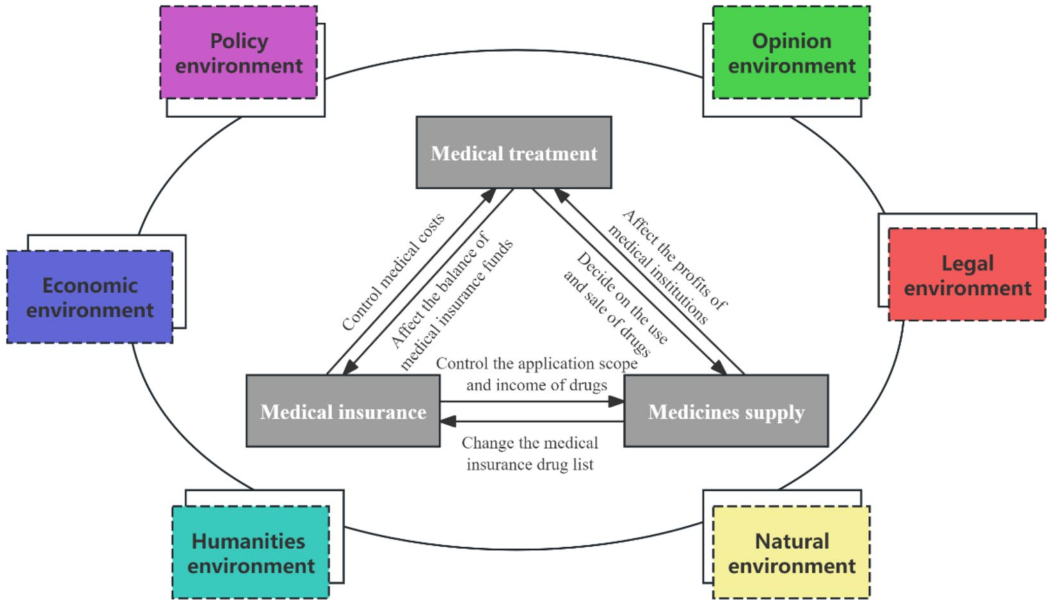

Fig. 1 The relationship of the Three-Medical systems

use and sales of drugs. Insurance coverage is an important indicator of the supply and use of essential medicine from the perspective of the relationship between medical insurance and medicines supply [34]. The entry of drugs into healthcare has a direct impact on investment in the pharmaceutical industry and can drive pharmaceutical innovation by actively promoting the use of medicines [35]. In addition, a close relationship exists between medical treatment and insurance. Whether people have medical insurance, and the degree of medical insurance, can significantly affect the utilization of medical services and their behavior in seeking medical treatment [36, 37]. The cost and quality of medical services also affect the choice of medical insurance payment method [38]. However, these studies only emphasize the theoretical impact of internal system interactions and lack empirical validation of the actual collaborative relationships. Therefore, integrating reforms across medical treatment, medical insurance, and medicines supply and assessing the coordination level is essential.

We conducted this study to assess the spatiotemporal evolution patterns of the Three-Medical linkage and subsystems, identify the main obstacles, and predict future trends. Evidence were drawn from panel data encompassing 31 provinces in mainland China from 2009 to 2021. The specific research objective were as follows: (1) Determining the level of coordinated development among the Three-Medical Linkage on a spatial-temporal scale and coordination of internal subsystems. (2) Identifying the main obstacles to the development of coordination. (3) Predicting future coordinated development trends. Clarifying these issues offers a comprehensive analysis of the coordination dynamics between the medical treatment, medical insurance, and medicines supply systems in China. Identifying the key obstacles and forecasting future trends will provide valuable insights for policymakers and researchers aiming to enhance healthcare system integration. These findings can also guide similar reforms in other developing countries and underscore the importance of balanced internal development within the healthcare system to achieve Sustainable Development Goal 3 (Good Health and Well-being).

Methodology

Data sources

The data used in this study were sourced from publicly available annual reports to ensure scientific reliability. These include *the China Health Statistical Yearbook*, *China Statistical Yearbook*, *China Labor Statistical Yearbook*, *China Social Statistical Yearbook*, *China High-Tech Industry Statistical Yearbook*, *China Pharmaceutical Yearbook* and *Provincial Statistical Yearbooks*. We used interpolation methods to address those missing values.

The division of regions into eastern, central, and western categories was based on the *China Health Statistical Yearbook*. The eastern region includes 11 provinces and municipalities: Beijing, Tianjin, Hebei, Liaoning, Shanghai, Jiangsu, Zhejiang, Fujian, Shandong, Guangdong, and Hainan. The central region comprises 8 provinces: Shanxi, Jilin, Heilongjiang, Anhui, Jiangxi, Henan, Hubei, and Hunan. The western region consists of 12 provinces, autonomous regions, and municipalities: Inner Mongolia, Guangxi, Chongqing, Sichuan, Guizhou, Yunnan, Tibet, Shaanxi, Gansu, Qinghai, Ningxia, and Xinjiang.

Research variables

This study adhered to the general standards for healthcare service ratings set by the World Health Organization and World Bank, as well as the specific requirements outlined in key documents such as *Healthy China 2030 Plan* and *the 14th Five-Year Plan period (2021–2025)*. Following the principles of comprehensiveness, scientific rigor, hierarchical structure, and practicality, we developed an evaluation index system for the coordinated development of the Three-Medical linkage. This was based on existing research [39–41] and consultations with relevant experts. Ultimately, we established three subsystems, nine primary indices, and 30 secondary indicators, as shown in Table 1. First, we selected "Fairness, Service Efficiency, and Sustainability" as dimensions based on the evaluation criteria of the World Health Organization. Specifically, fairness is reflected in the accessibility of medical services, measured by the availability of healthcare resources per thousand people. Service efficiency is primarily demonstrated by the efficiency of healthcare provision, particularly inpatient services. The sustainability of healthcare services is assessed based on the stability and long-term viability of medical expenses, with a particular focus on government expenditure. This aligns with the core principle of "Maintaining public welfare is the fundamental value orientation of China's healthcare system [42]." Second, we fully considered the primary social contradictions in China and leveraged existing

Table 1 Construction of the evaluation index system

Subsystem	Primary index	Secondary indicators	Units	Type	Weight
Medical treatment (T)	Fairness	T1 Number of Health Technicians per Thousand Population	person	+	0.110
		T2 Number of Hospital Beds per Thousand Population	bed	+	0.116
		T3 Number of Healthcare Institutions per Thousand Population	unit	+	0.150
	Service Efficiency	T4 Average length of stay	day	-	0.015
		T5 Bed utilization rate	%	+	0.030
		T6 Average number of diagnosis and treatment per physician per day	freq	+	0.177
		T7 Average number of inpatient days per physician per day	day	+	0.061
	Sustainability	T8 Proportion of medical income to total income	%	+	0.027
		T9 Proportion of medical and health expenditure to fiscal expenditure	%	+	0.096
		T10 per capita total health expenditure	CNY	+	0.218
Medical insurance (I)	Fairness	I1 Insurance coverage rate	%	+	0.039
		I2 Employee basic medical insurance per capita expenditure	CNY	+	0.096
		I3 Resident basic medical insurance per capita expenditure	CNY	+	0.167
	Safeguard Level	I4 reimbursement ratio	%	+	0.063
		I5 number of people benefiting from maternity insurance	10 thousand people	+	0.366
		I6 Direct medical assistance expenditure	10 thousand CNY	+	0.148
	Sustainability	I7 Revenue and expenditure ratio	%	+	0.080
		I8 Accumulated surplus ratio	%	+	0.037
		I9 The ratio of fund expenditure growth to GDP growth	%	-	0.002
		I10 The ratio of fund expenditure growth to fiscal expenditure growth	%	-	0.002
Medicines supply (S)	Scale & Efficiency	S1 Number of enterprises	unit	+	0.097
		S2 Number of employees	person	+	0.105
		S3 Pharmaceutical sales	10 thousand CNY	+	0.122
	Innovation capability	S4 R&D personnel full-time equivalent	person-year	+	0.154
		S5 new drug R&D costs	10 thousand CNY	+	0.223
		S6 Proportion of New Product Sales in Main Business Revenue	%	+	0.063
		S7 Number of patents	piece	+	0.186
	Development potential	S8 Personnel growth rate	%	+	0.007
		S9 Main Business Revenue Growth Rate	%	+	0.011
		S10 New product growth rate	%	+	0.032

The weights in Table 1 were calculated using the entropy weight method, and the specific calculation formula is provided in the entropy weight method section research on the high-quality development of the healthcare system [14, 43]. The basic medical insurance system must continually promote social equity, ensure adequate medical coverage, and achieve sustainable development. Therefore, we constructed an evaluation index system for medical insurance based on the following dimensions: "Fairness, Safeguard Level, and Sustainability." Third, considering the characteristics of pharmaceutical industry and relevant literature, we selected "Scale & Efficiency, Innovation capability and Development potential" as secondary indicators. This reflects the need for economies of scale and sustainable development of the industry [44].

Methods

Data standardization method

To address the issue of inconsistent measurements, which may cause comparison bias, we standardized the data. The standardization methods differ for the positive and negative indicators, as shown in Eq. (1). and Eq. (2).

$$\text{Positive indicators: } r_{ij} = \frac{a_{ij} - min(a_{ij})}{max(a_{ij}) - min(a_{ij})} \quad (1)$$

$$\text{Negative indicators: } r_{ij} = \frac{max(a_{ij}) - a_{ij}}{max(a_{ij}) - min(a_{ij})} \quad (2)$$

where a_{ij} denotes the raw value of the *i-th* indicator for the *j-th* province and r_{ij} represents the dimensionless value after standardization. $max\left(a_{ij}\right)$ and $min\left(a_{ij}\right)$ represent the maximum and minimum values of the *i-th* indicator across provinces, respectively. Indicator weights were calculated. To prevent p_{ij}=*0*, 0.0001 was added to the formula, as shown in Eq. (3).

$$p_{ij} = \frac{r_{ij}}{\sum_{i=1}^{m} r_{ij}} + 0.0001 \quad (3)$$

Entropy weight method

Entropy weight method is a commonly used objective-weighting method. It evaluates all assessed objects by calculating the relative distance between the optimal and worst solutions [45]. After normalizing the raw indicator data, the weight of each indicator was determined using the entropy weight method, as shown in Eqs. (4) and (5).

$$e_j = -\frac{1}{\ln m}\sum_{i=1}^{m} p_{ij}\ ln(p_{ij}) \quad (4)$$

$$w_j = \frac{1 - e_j}{\sum_{i=1}^{m} 1 - e_j} \quad (5)$$

where *m* is a constant related to the number of indicators and the scope of the study period. Subsequently, we calculated the overall score for each system using Eq. (6).

$$U_i = \sum_{i=1}^{m} w_j r_{ij} \quad (6)$$

Coupling coordination degree model (CCDM)

Coupling refers to a phenomenon in which two or more systems influence each other through various interactions. The degree of coupling reflects the degree of interdependence and mutual constraints between systems. However, the degree of coupling alone might not accurately reflect the developmental status of each system. When the values of the subsystems were relatively low, a high degree of coupling was observed. This situation clearly does not align with the optimal coordinated development. Therefore, a coordination index is introduced to provide a more comprehensive reflection of the coordination levels among the subsystems [46]. In recent years, with an increasing emphasis on high-quality healthcare development, more scholars have started using CCDM to study issues associated with coordinated development in the healthcare sector [47–49]. The coupling coordination degree (CCD) was calculated as follows:

$$C = \left[\frac{\prod_{i=1}^{n} U_i}{\left(\frac{1}{n}\sum_{i=1}^{n} U_i\right)^n}\right]^{\frac{1}{n}} \quad (7)$$

$$T = \sum_{i=1}^{n} \alpha_i U_i, \sum_{i=1}^{n} \alpha_i = 1 \quad (8)$$

$$D = \sqrt{C \times T} = \sqrt{\left[\frac{\prod_{i=1}^{n} U_i}{\left(\frac{1}{n}\sum_{i=1}^{n} U_i\right)^n}\right]^{\frac{1}{n}} \times \sum_{i=1}^{n} \alpha_i U_i} \quad (9)$$

where C denotes the coupling degree, which is distributed in the interval [0,1]. A higher C value indicates a smaller degree of dispersion between the subsystems. When calculating the coupling degree among the three medical systems, the expression was $C = \frac{3\sqrt[3]{U_T U_I U_S}}{U_T + U_I + U_S}$. U_T, U_I and U_S are comprehensive scores for medical treatment, medical insurance, and medicines supply, respectively. T denotes the coordination degree, while D represents the coupling coordination degree. In most studies, the importance of each subsystem is assumed to be the same [50], hence α_i was given the same weight. A higher D value indicates stronger coupling, a more robust synergistic relationship, and greater coordination in the development between systems. We categorized the CCD into 10 different levels [51]. These classifications are presented in Table 2.

Gravity model

The gravity model is effective for measuring spatial interactions. This model was derived from the law of universal gravitation by Newton [52], which states that the force between two objects is directly proportional to their masses and inversely proportional to the square of their distances. The gravity model has been widely applied in various fields such as tourism [53], technological cooperation [54], and rural development [55]. This study used the gravity model to calculate the strength of spatial connections in the CCD among provinces. This enables a more accurate understanding of the spatial patterns of the Three-Medical linkage. The formula is given by Eq. (10).

$$R_{ij} = K\frac{D_i D_j}{{G_{ij}}^2} \tag{10}$$

where R_{ij} represents spatial association strength of the CCD between provinces *i* and *j*. *Di* and *Dj* denote CCD of provinces *i* and *j*, respectively. G_{ij} is actual distance between provinces *i* and *j*, measured in kilometers between their capital cities. *K* is the gravity constant, typically set to 1.

Prediction model

Considering the data types and distribution characteristics, we employed the mean GM (1,1) and Holt linear trend methods to forecast changes in the coordination development of the Three-Medical linkage from 2022 to 2030. Using Grey System Software 7.0 and SPSS 26.0, the above models were constructed to calculate forecasting values. This study employed a combination forecasting method to aggregate and weigh the predicted values to mitigate the performance decline that may result from using a single model. This method effectively prevents the issue of different single models by focusing on various aspects of the data. It also allows information to complement each other, thereby enhancing the overall predictive accuracy of forecasts [56]. Here, we used the inverse of mean-squared error method to assign weights, which is a commonly used approach in combination forecasting. Details are provided in Eq. (11).

$$W_j = \frac{S_j^{-\frac{1}{2}}}{\sum_{j=1}^{J} S_j^{-\frac{1}{2}}}, j = 1,2,3,\cdots\cdots J \tag{11}$$

where S_j represents the sum of squared errors of the *i-th* model. Models with smaller sums of squared errors received higher weights, whereas those with larger sums received lower weights.

Table 2 Classification of coupling coordination degree

Types of coordinated development	Degree of coupling coordination	Grade
Disordered development	0 ≤ D <0.1	C1 extreme incoordination
	0.1 ≤ D <0.2	C2 severe incoordination
	0.2 ≤ D <0.3	C3 moderate incoordination
	0.3 ≤ D <0.4	C4 slight incoordination
Transitional development	0.4 ≤ D <0.5	C5 approaching incoordination
	0.5 ≤ D <0.6	C6 slight coordination
Coordinated development	0.6 ≤ D <0.7	C7 primary coupling coordination
	0.7 ≤ D <0.8	C8 moderate coupling coordination
	0.8 ≤ D <0.9	C9 good coupling coordination
	0.9 ≤ D ≤ 1	C10 superior coupling coordination

Obstacle degree model

The CCDM can only analyze the CCD among the systems of various provinces, but it cannot further explore the influencing factors. Compared with methods such as the subtractive set pair potential and partial connection numbers, the obstacle degree model is a simple and effective approach for identifying key influencing factors [57]. This study employed an obstacle degree model to identify the critical factors impeding the coordinated development of the three medical sectors and proposed targeted actionable measures to facilitate harmonious progress. The formula is shown in Eq. (12).

$$Q_{ij} = \frac{(1-r_{ij})\times\ w_{ij}}{\sum_{j=1}^{n}(1-r_{ij})\times\ w_{ij}} \tag{12}$$

where $1 - r_{ij}$ represents the deviation degree, calculated as the difference between the standardized value of a single indicator and 100%. w_{ij} is the corresponding weight of this indicator and Q_{ij} is the degree of the obstacle.

Results

Comprehensive evaluation results

We drew three-dimensional dynamic kernel plots to visually represent the overall development level, distribution evolution, extension, and polarization trends (Fig. 2). The following observations were made:

(1) The distribution centers of the comprehensive evaluation values for the three medical systems exhibited a consistent rightward shift. This signifies a general upward development trend. Notably, a significant move to the right and a stable upward trend have been observed in the medical treatment and insurance systems. This phenomenon reflects

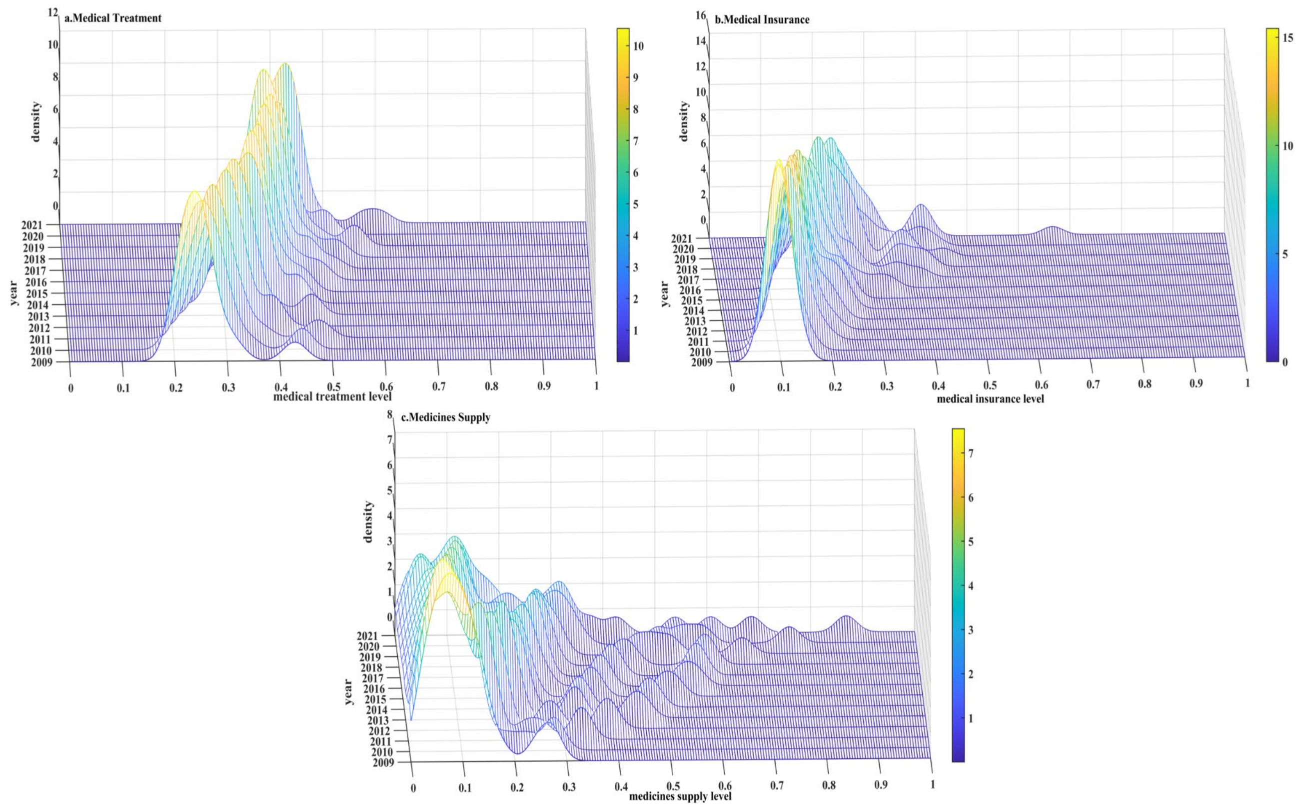

Fig. 2 Dynamic evolution plot of overall development levels

the ongoing improvements in the medical and health insurance systems of China, with a stable growth trajectory. However, the distribution center for the medical treatment system shifted significantly to the left in 2020. The decline in the overall development may be rooted in the COVID-19 pandemic. This emergency adds pressure to the healthcare system and results in the disruption of medical services [58].

(2) The comprehensive development levels of the three medical systems exhibited a right-tailed distribution pattern. However, an obvious system heterogeneity existed. The medical insurance system exhibited a less pronounced right tail, indicating a more balanced development across provinces. In contrast, medical treatment and medicines supply systems exhibited more pronounced right tails, reflecting notable disparities in development levels among the provinces. Despite the overall lower evaluation of pharmaceutical systems, some regions demonstrated much higher development levels, contributing to the most severe right tails in the medicines supply system.

(3) Only a single peak existed in the medical insurance system between 2009 and 2015. This indicates that no significant polarization characteristics existed in the development of the medical insurance system. Its dynamic evolution map exhibited multiple side peaks in 2016, signifying the emergence of polarization. In contrast, the medical treatment and medicines supply systems exhibited multiple side peaks from 2009 to 2021, indicating clear polarization characteristics. Additionally, peak shapes of the medical insurance system were the narrowest, followed by those of medical treatment and pharmaceutical systems. However, over the sample period, the peaks of the medical insurance system gradually widened, suggesting an increasing trend in regional disparities.

(4) All three medical systems exhibited a shift toward multiple peaks, with a gradually wider span between the peaks. This suggests the potential presence of the "Matthew Effect." The most notable aspect is the medicines supply system. It exhibited a bimodal distribution in 2009, which gradually transitioned to a multimodal distribution over time. The number of peaks increased significantly in 2021, with clear distances between them. This trend reflects the intensifying multi-level differentiation and the progressively widening gap in development levels across regions.

Coupling coordination results

We primarily evaluated the coupling coordination situation of the three medical systems at a comprehensive level, along with internal pairwise evaluations.

The Three-Medical linkage systems

We calculated the CCD of the three medical systems in each province from 2009 to 2021. Table 3 presents the results of the study. Additionally, by applying the classification criteria for CCD outlined in Table 2, a heat map was generated using the Origin software to visually represent these findings (Fig. 3). The results demonstrated the following:

(1) From a temporal perspective, the CCD of three medical systems gradually increased, with values ranging between 0.25 and 0.75. In 2009, the maximum and minimum CCD were 0.454 and 0.270, respectively. By 2021, these values had risen to 0.744 and 0.347, respectively. This change may be attributed to the fact that, since the implementation of the "New Medical Reform" policy in 2009, China has significantly increased its focus on the healthcare sector, continuously intensified investment, and progressively enhanced institutional frameworks [14]. In terms of coupling coordination level, most provinces in 2009 were in the 0.3–0.4 range, classified as the disordered development stage. Over time, the coordination level improved and transitioned to intermediate stages. Some provinces surpassed a coupling coordination level of 0.6 and entered the coordinated development phase. However, most provinces only reached the primary coupling coordination grade (C7), with only a few provinces achieving a moderate coupling coordination grade (C8).

(2) From a spatial perspective, Guangdong, Jiangsu, Zhejiang, Shandong, Beijing, Shanghai, and Sichuan consistently ranked highest in terms of CCD. Most of these provinces are located in the eastern region, which is characterized by relatively advanced economic conditions and well-developed healthcare systems. This finding indicated that the level of coordination among the three medical systems may be closely associated with economic development. The regional disparities in the CCD across China widened between 2009 and 2021. In 2009, Zhejiang had the highest CCD at 0.454, whereas Qinghai had the lowest CCD at 0.270, with a gap of 0.183. By 2021, Guangdong had a score of 0.744, whereas Tibet had the lowest score at 0.347, with the gap increasing to 0.396. Although most provinces have improved their coordination, the trend has been inconsistent. Guangdong exhibited the fastest growth, with an increase of 76.5%. As the largest economy of China, Guangdong has the largest population and has consistently ranked the highest in the GDP rankings for several years. It also boasts top-tier health indicators and superior medical infrastructure [59]. These factors provide a robust foundation for the three-medical linkage. However, the growth trend in certain provinces was relatively sluggish, with the CCD in Tibet exhibiting a downward trend. This indicates that despite substantial support for Tibetan medicine from local and national governments, other provinces, and international institutions over the past few decades [60], the issue of coordinated development in the healthcare system may still require further attention.

The internal pairwise systems

We measured CCD between each pair of subsystems (Fig. 4). From a temporal perspective, the CCD for all three internal pairwise systems increased annually. However, growth trends varied among the different pairs. The CCD between the medical treatment and insurance systems was relatively stable and consistently increased over time. Specifically, the coordination level between medical insurance and medicines supply systems was lower compared to others in 2009, with a range of 0.2–0.4. However, the minimum CCD between medical treatment and insurance systems exceeded 0.35 in the same year. By 2021, all 31 provinces had a better correlation between the medical treatment and insurance systems, with most reaching a slight coordination level (C6). However, the CCD of medical treatment and medicines supply systems differs significantly and the distribution of provinces ranged from moderate incoordination (C3) to moderate coordination (C8). This observation indicates that in the three medical linkage, the medical treatment and insurance systems had established relatively stable connections, but the connection with the medicines suppply system was insufficient. This may be associated with previous imperfect systems in the pharmaceutical industry in China and insufficient government supervision [61].

From a spatial perspective, the trends in the development of coordination between medical treatment and medicines supply systems and between medical insurance and medicines supply systems were quite consistent. Specifically, Beijing, Guangdong, Jiangsu, Shandong, Zhejiang, and Sichuan provinces exhibited significantly higher levels of coordination development than others, aligning with the overall degree ranking of the Three-Medical linkage system, which suggests that to achieve a high level of the three-medical linkage, coordination among the subsystems should be enhanced.

Spatial connectivity results

This study estimated the spatial connectivity strength of the Three-Medical linkage across 31 provinces in mainland China. Owing to space constraints, the analysis is illustrated using data from five periods: 2009, 2012, 2015, 2018, and 2021. Strength was classified into five levels using the natural breaks classification method. To

Table 3 Coupling coordination degree of the Three-Medical systems

Region	Province	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Eastern Region	Beijing	0.423	0.424	0.455	0.469	0.515	0.520	0.524	0.545	0.569	0.613	0.630	0.614	0.680
	Fujian	0.350	0.342	0.372	0.384	0.403	0.415	0.420	0.449	0.438	0.451	0.469	0.476	0.496
	Guangdong	0.421	0.439	0.474	0.492	0.520	0.540	0.558	0.598	0.633	0.647	0.672	0.670	0.744
	Hainan	0.302	0.277	0.306	0.317	0.338	0.350	0.354	0.362	0.378	0.380	0.387	0.392	0.435
	Hebei	0.372	0.383	0.399	0.416	0.430	0.446	0.455	0.476	0.491	0.497	0.514	0.524	0.540
	Jiangsu	0.447	0.463	0.505	0.535	0.564	0.586	0.599	0.640	0.658	0.678	0.691	0.700	0.730
	Liaoning	0.358	0.356	0.367	0.380	0.395	0.406	0.406	0.411	0.431	0.444	0.449	0.461	0.467
	Shandong	0.414	0.433	0.470	0.498	0.530	0.579	0.569	0.601	0.617	0.628	0.622	0.638	0.670
	Shanghai	0.430	0.435	0.485	0.481	0.503	0.514	0.522	0.560	0.589	0.599	0.612	0.601	0.647
	Tianjin	0.340	0.360	0.397	0.410	0.446	0.453	0.461	0.475	0.474	0.475	0.471	0.470	0.500
	Zhejiang	0.454	0.462	0.490	0.515	0.545	0.564	0.576	0.594	0.617	0.638	0.650	0.663	0.681
Central Region	Anhui	0.336	0.350	0.395	0.415	0.435	0.450	0.461	0.477	0.503	0.523	0.539	0.563	0.578
	Henan	0.375	0.382	0.414	0.436	0.453	0.473	0.486	0.507	0.521	0.535	0.553	0.555	0.575
	Heilongjiang	0.350	0.337	0.366	0.373	0.389	0.395	0.398	0.403	0.406	0.407	0.416	0.418	0.444
	Hubei	0.367	0.382	0.418	0.444	0.457	0.480	0.495	0.513	0.536	0.541	0.560	0.582	0.589
	Hunan	0.372	0.367	0.403	0.417	0.431	0.452	0.467	0.487	0.498	0.505	0.531	0.533	0.556
	Jilin	0.368	0.347	0.388	0.406	0.423	0.422	0.429	0.443	0.434	0.440	0.453	0.460	0.476
	Jiangxi	0.365	0.369	0.401	0.403	0.416	0.434	0.446	0.463	0.484	0.495	0.507	0.519	0.537
	Shanxi	0.311	0.314	0.344	0.355	0.365	0.382	0.389	0.393	0.414	0.429	0.433	0.446	0.450
Western Region	Gansu	0.285	0.300	0.321	0.340	0.342	0.356	0.362	0.375	0.391	0.408	0.401	0.407	0.440
	Guangxi	0.331	0.344	0.371	0.378	0.388	0.402	0.401	0.412	0.419	0.433	0.448	0.455	0.479
	Guizhou	0.298	0.319	0.335	0.349	0.367	0.381	0.395	0.414	0.431	0.452	0.474	0.469	0.487
	Inner Mongolia	0.282	0.284	0.308	0.317	0.335	0.340	0.344	0.364	0.373	0.382	0.388	0.400	0.409
	Ningxia	0.312	0.337	0.327	0.339	0.358	0.375	0.369	0.383	0.380	0.376	0.371	0.369	0.376
	Qinghai	0.270	0.270	0.275	0.303	0.303	0.302	0.324	0.334	0.317	0.327	0.354	0.350	0.350
	Shaanxi	0.345	0.343	0.361	0.378	0.401	0.416	0.427	0.440	0.455	0.463	0.475	0.468	0.489
	Sichuan	0.409	0.412	0.455	0.479	0.494	0.520	0.532	0.530	0.559	0.573	0.589	0.607	0.624
	Tibet	0.355	0.346	0.329	0.333	0.334	0.344	0.289	0.321	0.334	0.326	0.345	0.331	0.347
	Xinjiang	0.281	0.277	0.309	0.315	0.338	0.341	0.355	0.356	0.377	0.396	0.404	0.381	0.389
	Yunnan	0.335	0.340	0.385	0.389	0.398	0.416	0.428	0.432	0.458	0.472	0.473	0.489	0.503
	Chongqing	0.353	0.352	0.374	0.416	0.431	0.445	0.457	0.472	0.484	0.496	0.507	0.517	0.518
Maximum		0.454	0.463	0.505	0.535	0.564	0.586	0.599	0.640	0.658	0.678	0.691	0.700	0.744
Minimum		0.270	0.270	0.275	0.303	0.303	0.302	0.289	0.321	0.317	0.326	0.345	0.331	0.347
Average		0.355	0.360	0.387	0.403	0.421	0.435	0.442	0.459	0.473	0.485	0.496	0.501	0.523

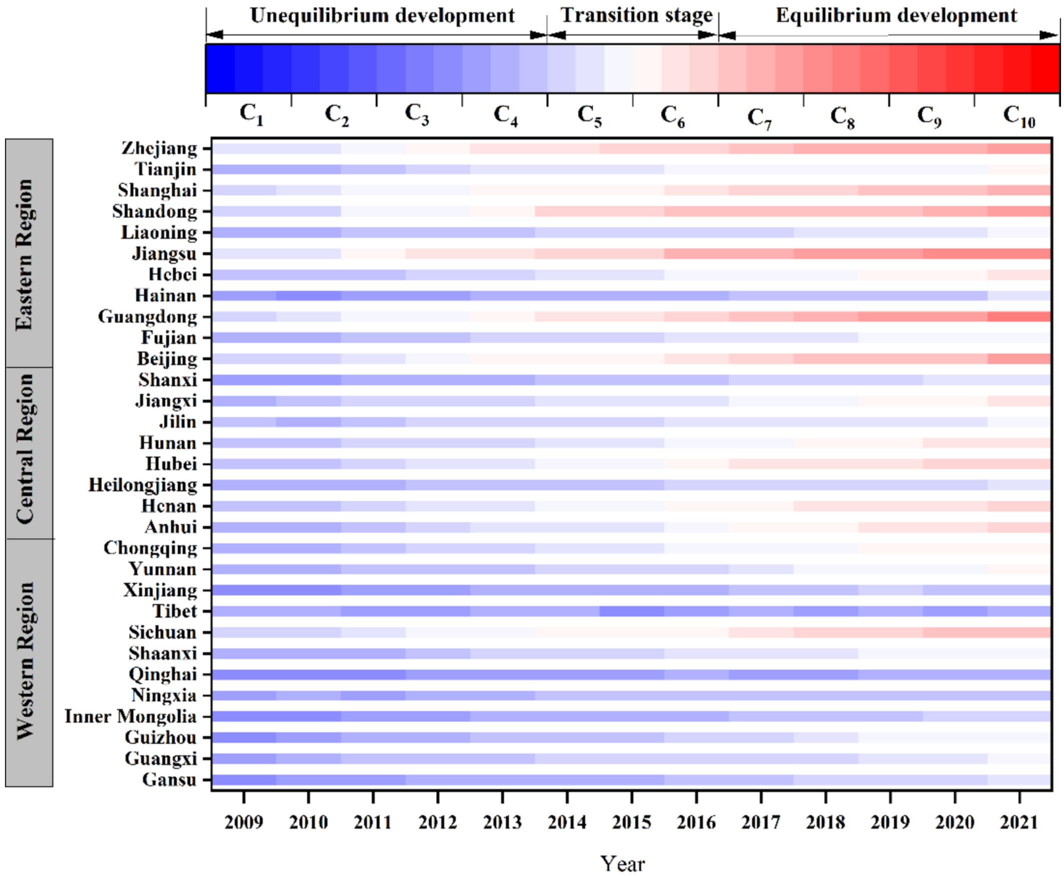

Fig. 3 Coupling coordination grades of the Three-Medical systems

facilitate observations, spatial connectivity with weak ties was omitted (Fig. 5).

From a temporal perspective, in 2009, the strongest connections were emerged between Beijing and Tianjin, Shanghai and Zhejiang, and Jiangsu and Anhui. In 2012, except for the weakened connections between Hunan and Hubei, Hunan and Jiangxi, and Jilin and Liaoning, the overall spatial connection network remained similar to the 2009 network. In 2015, the spatial connection intensity among provinces remained largely consistent with that observed in 2012, indicating a degree of stability in interprovincial linkages. By 2018, the connections between the three northeastern provinces weakened, dropping to the third tier. However, this connectivity had strengthened again by 2021. In the same year, the increasing influence of Beijing led to a closer connection with Shandong and the spatial connections among Hubei, Hunan, and Jiangxi were re-strengthened, forming a stronger “triangular” distribution. This phenomenon may be attributed to the Paired Assistance Policy during the COVID-19 pandemic. China provided large-scale assistance to 16 cities in Hubei Province outside Wuhan, effectively addressing the public health emergency [62]. Furthermore, the above results also suggest that the outbreak of public health emergencies may have enhanced the spatial linkages for the coordinated development of healthcare sectors across provinces, leading to strengthened integration among neighboring regions.

From a spatial perspective, interprovincial connections have continuously increased over the years. The eastern provinces exhibited the strongest spatial connections, whereas the western provinces had weaker spatial ties. Overall, the Beijing-Tianjin-Hebei and Yangtze River Delta regions serve as high-intensity connection hubs with relatively stable interprovincial connections within these areas. Additionally, while the Hubei-Hunan-Jiangxi region and three northeastern provinces exhibit strong connections, their stability is comparatively weak.

Combination forecasting results

We employed a combination of the Holt linear trend method and the GM (1,1) grey forecasting model to improve prediction accuracy, with both methods passing the model validation. Considering the policy guidance of the plan for a Healthy China 2030, we set 2022–2030 as the forecast period.

The forecast results are as follows. (1) Overall, the CCD of the three medical systems from 2022 to 2030, whether

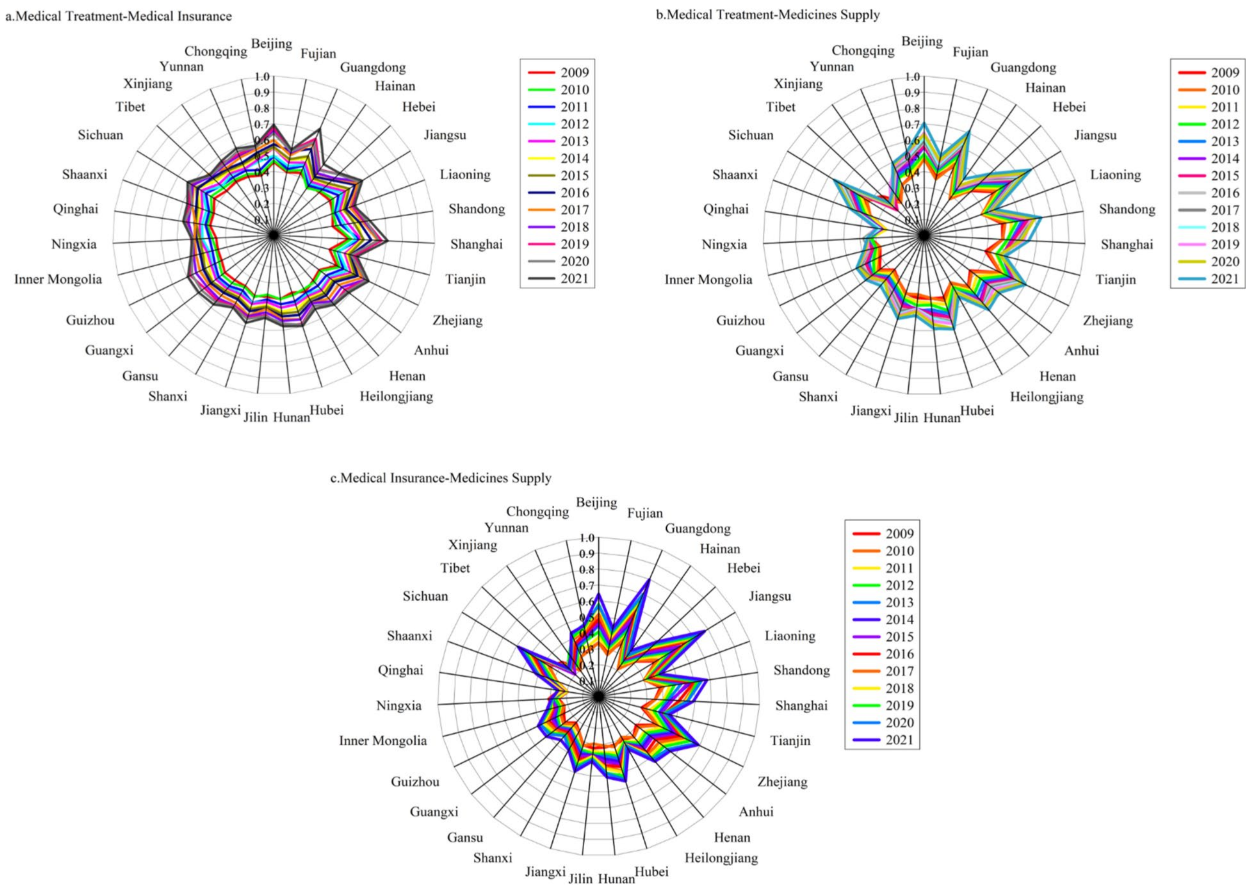

Fig. 4 The coupling coordination degrees in internal pairwise systems

in the ternary or binary subsystems, shows a year-by-year increase in predicted values. However, the growth rates will vary across systems (Fig. 6), with medical treatment and medicines supply linkage exhibiting the slowest growth. (2) The predicted values for all systems in the eastern and central regions will exceed 0.6 by 2030, reaching a stage of coordinated development. In contrast, growth in the western region will remain slow, and almost all systems will remain in a transitional stage, except for medical treatment and insurance linkage. Notably, the coordination level of the medical insurance and medicines supply systems of the eastern region is predicted to increase rapidly from 2022 to 2030. It will nearly achieve good coupling coordination(C9), with an increase of 0.2 over these 9 years. (3) When ranking these systems by regional gaps from smallest to largest, the order is medical treatment and insurance linkage, the Three-Medical linkage, medical treatment, and medicines supply linkage, and medical insurance and medicines supply linkage. The forecasting results for medical treatment and insurance linkage indicate that the central and western regions will experience convergence between 2022 and 2030. However, regional disparities within all the systems are likely to continue widening.

Identification of the obstacles

Based on the aforementioned results, we calculated the obstacle degrees for the 30 indicators in the Three-Medical linkage (Fig. 7). Notably, the obstacles for each province in each year was converted to a mean because they encompassed multiple years. The ranking of obstacle degrees for the different subsystems exhibited significant heterogeneity. The three main obstacles in the medical treatment system were per capita total health expenditure (T10), average number of patients handled per physician per day (T6), and number of healthcare institutions per thousand people (T3). The primary obstacles in the medical insurance system were the number of people benefiting from maternity insurance (I5), per capita expenditure of basic medical insurance for residents (I3), and direct medical assistance expenditure (I6). Simultaneously, the three primary obstacles in the medicines supply system were new drug research and development (R&D) costs (S5), number of patents held (S7), and full-time R&D personnel usage (S4).

From the comparison in Additional file 1, the obstacle degree of the number of people benefiting from maternity insurance is the highest among all the indicators, with an average value of 42.2%. Increasing the number

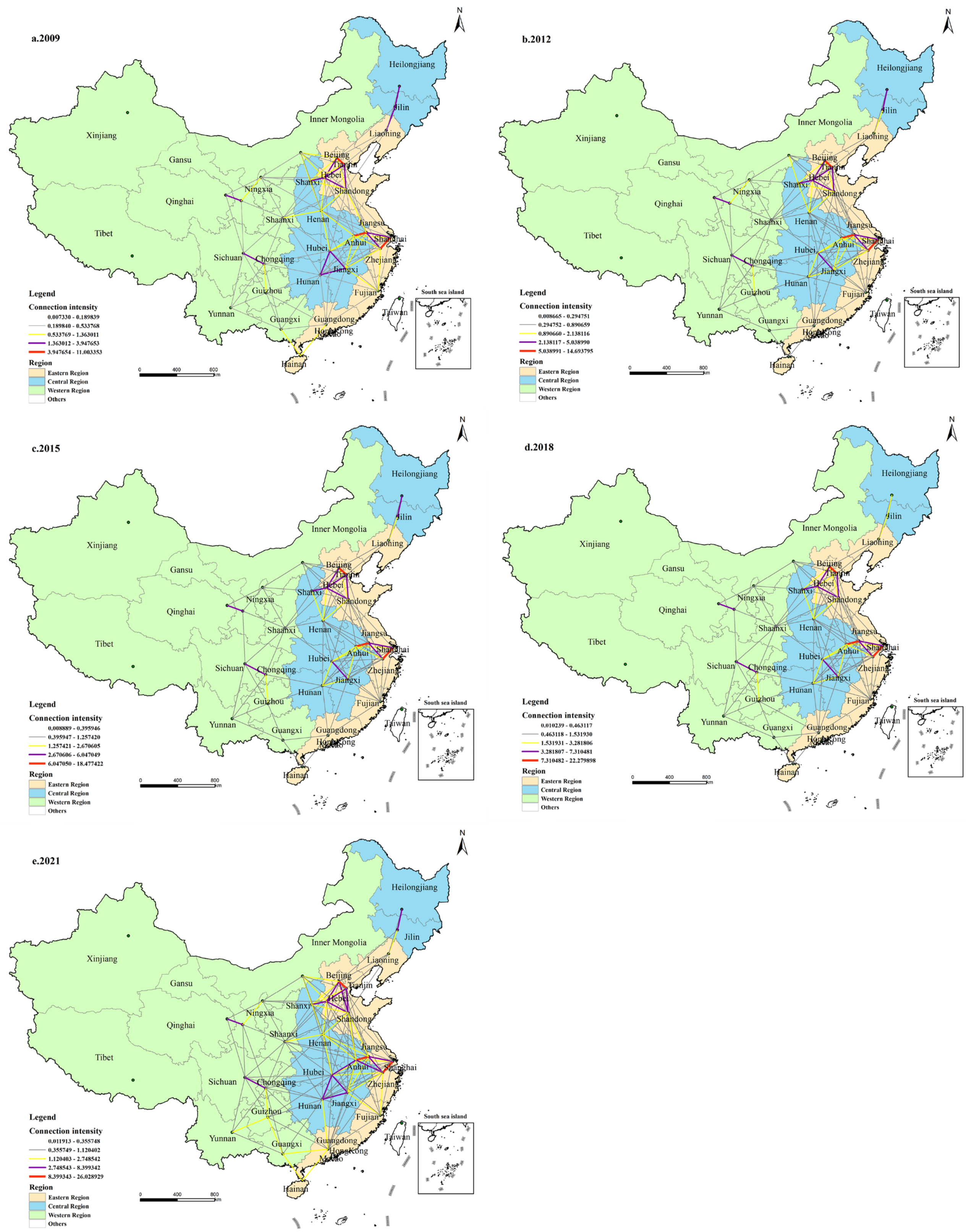

Fig. 5 Spatial connectivity of the Three-Medical linkage coupling coordination

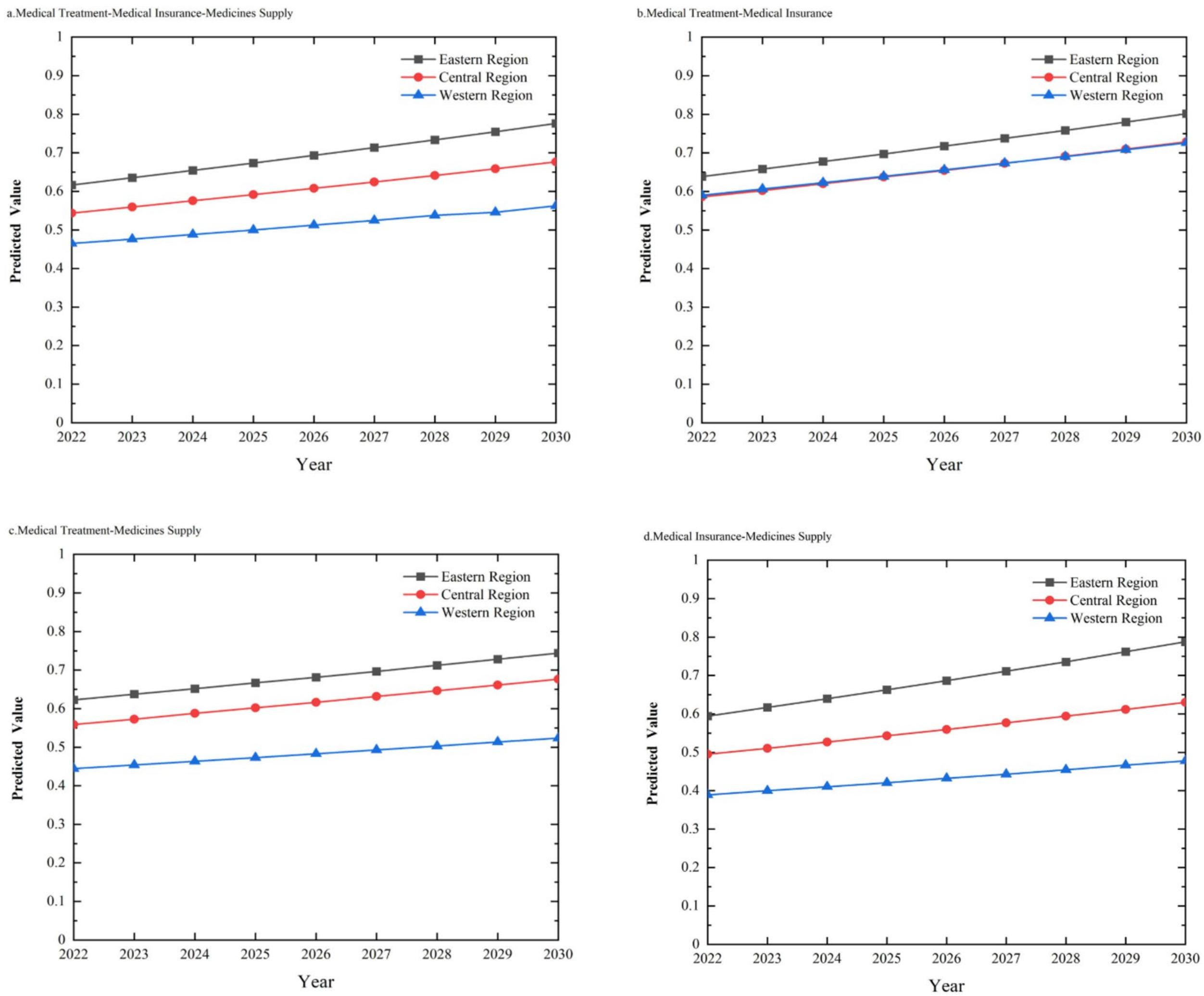

Fig. 6 Future trends forecast of the Three-Medical linkage and between subsystems coupling coordination from 2022 to 2030

of people with maternity needs is a key concern that should be addressed in the future. In addition, the obstacle degrees for new drug R&D costs and per capita total health expenditure exceeded 20% in most provinces, ranking second and third among all indicators, respectively. These hindered the Three-Medical linkage. Even in economically developed first-tier cities, such as Beijing and Shanghai, a serious shortage persisted.

Discussion

Address provincial differences in the Three-Medical linkage

This study revealed significant provincial disparities in the spatiotemporal evolution of the Three-Medical linkage, which merits further exploration. These differences could be attributed to several factors.

First, heterogeneity in economic development across provinces creates disparities in resource allocation, policy implementation, and infrastructure quality. For instance, Jiangsu Province, with its strong economic foundation, advanced healthcare infrastructure, and demonstrates effective coordination among the medical treatment, insurance, and supply systems. Key success factors include proactive government policies, substantial financial investment, and innovative public-private partnerships [63]. In contrast, Guizhou Province, characterized by a relatively underdeveloped economy, faces systemic challenges such as limited resources and fragmented policy enforcement [64]. Nonetheless, targeted programs, such as telemedicine initiatives, have shown promise in addressing healthcare accessibility in underserved areas.

Second, demographic and geographical variations play crucial roles. Provinces with aging populations or higher disease burdens, such as Liaoning [65], often struggle with increased demand for healthcare services and insurance coverage, which complicates the coordination of the Three-Medical systems. Geographically isolated regions such as Xinjiang face logistical challenges that weaken the integration of medical systems [8].

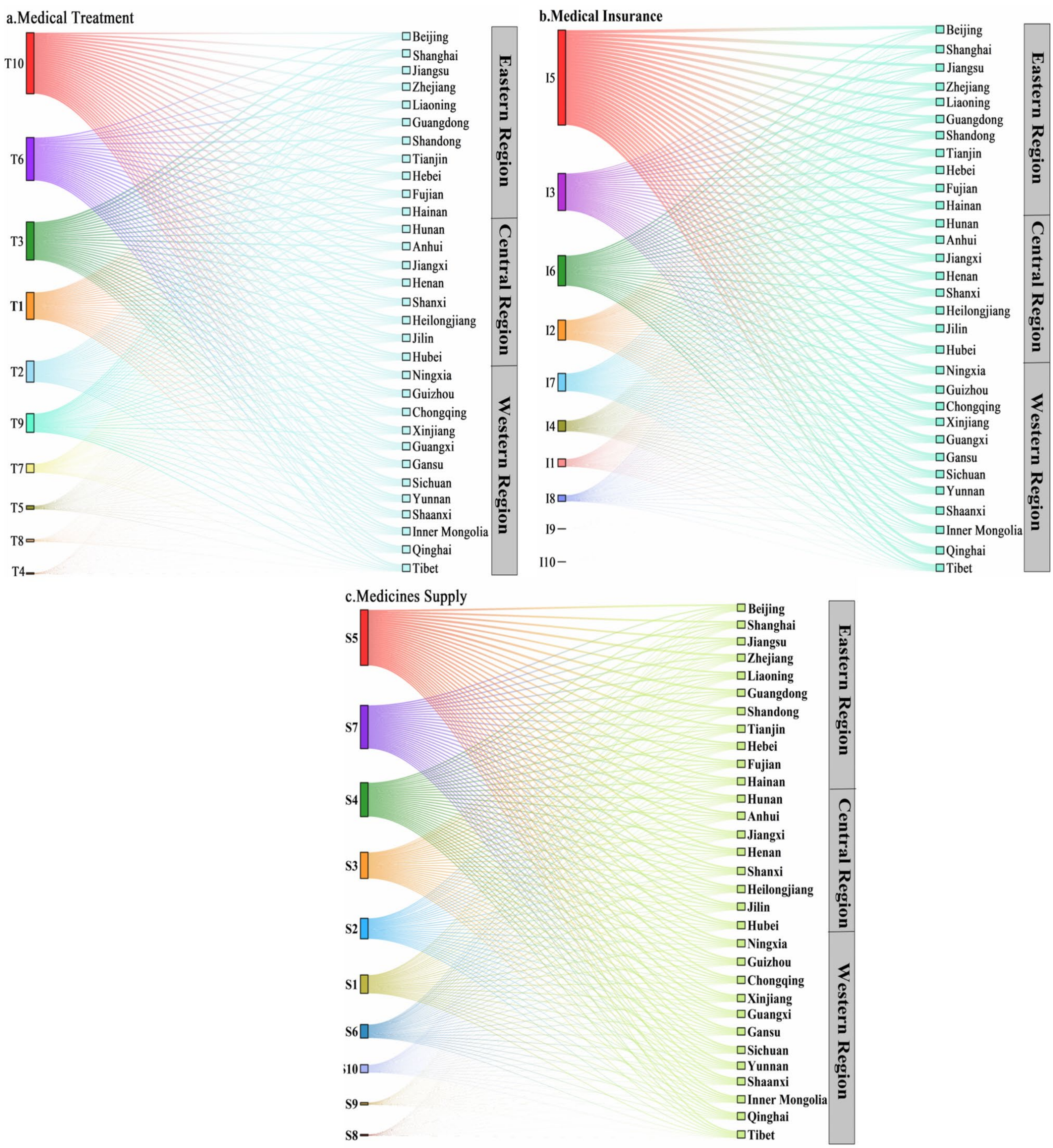

Fig. 7 The obstacle factors in each subsystem

Third, the extent of government intervention and policy prioritization varies across regions, influencing the depth and effectiveness of the implementation of the Three-Medical linkage. Provinces with proactive policy frameworks and higher administrative efficiency, such as Zhejiang, often achieve better coordination outcomes. By contrast, regions with weaker governance structures may struggle to overcome barriers to integration. For instance, disparities in funding allocation and limited interdepartmental collaboration in underperforming provinces highlight the importance of tailored interventions to strengthen governance and institutional support.

To address these provincial disparities and promote the equitable development of the Three-Medical linkage, a multi-pronged approach is essential. Policymakers should prioritize region-specific strategies such as increasing financial investment in underdeveloped areas, fostering cross-sector collaboration, and enhancing the adaptability of healthcare policies to local demographic and geographical conditions. In addition, successful practices in provinces such as Jiangsu and Zhejiang should be systematically evaluated and adapted to regions with similar challenges to ensure scalable and sustainable solutions. Leveraging technologies, such as telemedicine and digital health platforms, can further bridge gaps in accessibility and efficiency, particularly in remote or resource-constrained areas. These targeted measures will contribute to developing a harmonious and coordinated Three-Medical linkage framework across China.

Adapt multiple measures to improve coupling coordination degree of the Three-Medical linkage

Macro-level

On the one hand, as shown in Fig. 2, the medical insurance system of China exhibits the most stable growth and smallest regional disparity. This reflects the efforts of the government to build the largest medical security network of the world from a near-zero base, which is praised by the World Bank as unparalleled [66]. Over the past decade, healthcare reforms have established a nearly universal health insurance system with broad and multi-tiered coverage [67]. Currently, basic medical insurance covers > 95% of the population annually, with more than 1.33 billion individuals insured. Previous studies have confirmed its high coverage and effectiveness [68–70]. However, the medical insurance system is exhibiting signs of "multi-polarization" indicating persistent development imbalances. Future efforts should focus on narrowing benefit disparities between systems and regions. In addition, the medical treatment system exhibited the highest level of development but experienced a noticeable decline in 2020. Therefore, the impacts of the COVID-19 pandemic can be speculated. According to the first key survey of the World Health Organization, 90% of healthcare systems in the world have been affected by the pandemic [71]. Enhancing the resilience of healthcare system during the post-pandemic era is important [72]. Therefore, establishing a robust national emergency response network is essential [73]. This would ensure that resources, such as medical supplies, equipment, and personnel, are mobilized efficiently across regions. The government should foster international collaboration and develop an early warning plan to mitigate health inequalities.

On the other hand, the aging population of China, along with improvement in living standards and disposable income, has made pharmaceutical industry one of the most affected sectors [74]. However, as shown in Fig. 2, compared to the medical treatment and insurance systems, the overall development of the medicines supply system remains unsatisfactory. Significant disparities exist among the provinces, indicating highly uneven regional development. This aligns with the previous findings of Yi Z and Li L [75]. Therefore, developing a top-level design, implementing national-level strategic planning, and providing institutional and political support are essential. Targeted support should be provided to provinces with underdeveloped pharmaceutical sectors. All of these measures will further promote pharmaceutical industry chain improvement and a specialized division of labor. Simultaneously, the CCD of the Three-Medical linkage still needs improvement, especially in terms of regional equality. According to the forecast results, the eastern region is expected to reach nearly 0.8 by 2030, falling into the moderate coupling coordination grade (C8). Although the western region will still be below 0.6, the transitional development stage remains. Therefore, the comprehensiveness, systematicity, and coordination of reforms must be enhanced.

Micro-level

An insufficient number of people benefiting from maternity insurance has significantly hampered the coordination of the Three-Medical linkage. This is rooted in the global reality of birth rates drop-off [76], with China being no exception. To increase the birth rate, the Chinese government implemented several policies, including the introduction of the three-child policy in May 2021 [77]. Zhang et al. suggested that, in order to broaden the coverage of maternity insurance, a potential strategy could be the reduction of premium rates, which may effectively stimulate higher demand for maternity insurance [78].

Additionally, per capita total health expenditure and new drug R&D costs are adverse factors. This aligned with the actual situation. First, despite remarkable economic growth in China over the past few decades and a marked increase in healthcare expenditure [79], the per capita total health expenditure of China remains inadequate [80]. In 2021, expenditure was $843.21, which is 63.74% of the world average and ranks 69th among WHO member states. Second, drug discovery and development are lengthy and costly [81]. Previous findings indicate that most provinces in China currently have insufficient funding for the R&D of new drug. Therefore, continued efforts are needed to increase funding for new drug R&D and total health expenditure.

Limitations

First, this study identified the main obstructive factors affecting the Three-Medical linkage, but only within the medical system. Further analysis of both internal and external dimensions is needed to explore the factors influencing the Three-Medical linkage. Second, to ensure horizontal comparisons among provinces, all data were sourced from public yearbooks, which inevitably introduced a lag. Third, we built an evaluation framework and utilized various yearbooks to consider the different dimensions as comprehensively as possible. However, this may include subjective bias. A more objective and comprehensive measurement indicator and data source need to be explored to facilitate broader international comparisons. Additionally, despite ongoing improvements in the healthcare system and new policies, we have not yet analyzed the impact of policy changes on the Three-Medical linkage.

Conclusions

This study explains the spatial-temporal evolution patterns of the Three-Medical linkage between subsystems, identifies the main obstacles, and predicts future trends in 31 provinces of China from 2009 to 2021. The findings were as follows:

(1) All the Three-Medical systems showed continuous growth trends, with $U_T > U_I > U_S$. The medical insurance system exhibited the lowest regional disparity, as indicated by its narrow peak, although the differences are gradually increased.

(2) The CCD of the Three-Medical linkage and between subsystems have a fluctuating upward trend in China. The CCD in economically developed regions, such as Beijing, Guangdong, Jiangsu, Shandong, and Zhejiang, is significantly higher compared to other provinces. This suggests a potentially close relationship between economic development and the coordinated operation of the three medical sectors.

(3) The insufficient number of individuals covered by maternity insurance, inadequate health expenditure, and new drug R&D costs are the primary obstacles hindering the coupling coordination development.

(4) The spatial connectivity is strongest between the Beijing-Tianjin-Hebei region and Yangtze River Delta. However, connection instability is observed in the northeastern provinces as well as in the Hubei, Hunan, and Jiangxi regions, with prospects for further strengthening.

(5) The disparities in CCD between different regions of China will continue to widen. The CCD of the Three-Medical linkage and internal pairwise systems will range from 0.4–0.8 from 2022 to 2030. No regions have attained the grade of "good coupling coordination" (C9).

Abbreviations

Three-medical linkage	Medical treatment, medical insurance, and medicines supply linkage
CCDM	Coupling coordination degree model
CCD	Coupling coordination degree

Supplementary Information

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Additional file 1. Obstacle factors of the Three-Medical systems.

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Authors' contributions

LG conceptualized this study, performed the statistical analysis and drafted the manuscript. FK participated to data analysis and helped to revise the draft. LZ and RX participated to study design and helped to revise the draft. KZ contributed to drafting background section of the manuscript. RL and QZ participated in the design and implementation. All authors read and approved the final manuscript.

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Data availability

The datasets supporting the conclusions of this article are publicly available from various public yearbooks in China.

Declarations

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

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