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Analysis of the patient-sharing network in hypertension management: a retrospective study in China

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ABSTRACT

Objective To explore the robustness of the patient-sharing network and validate the association between strength and persistence of physicians' relationships in China.

Design, setting and participants We conducted a patient-sharing network analysis to describe the persistence of patient-sharing relationships and logistic regression to analyse factors associating with the persistence of patient-sharing relationships in the Yinzhou Health Information System from 1 January 2010 to 31 December 2018; all outpatient records that had a hypertension diagnosis were included in this study.

Outcome measures The persistence ratio was defined as the proportion of the patient-sharing relationships in a given year that continued to exist in the following year, the 1-, 2- and 3-year persistence to test the robustness of the findings.

Results This study included 3916 physicians from 42 public healthcare facilities in Yinzhou. The 1-year persistence ratio fluctuated around 80%, and the 3-year persistence ratio was around 60% over the study period. The strength of the relationship, tie characteristics and physician specialty were important factors associating with the persistence of the relationships. The persistence of the relationships increased significantly as the strength of the relationships increased (for relationships with strength $\in$ [3, 5), OR=3.987, 95% CI 3.896 to 4.08; for relationships with strength $\in$ [5, 7), OR=6.379, 95% CI 6.147 to 6.626; and for relationships with strength $\in$ [7, 9), OR=8.373, 95% CI 7.941 to 8.829). Physicians from the same healthcare institution were more likely to form ties that persisted for at least 1 year compared with physicians from different institutions (OR=1.510, 95% CI 1.480 to 1.540).

Conclusions Our study showed that physicians frequently formed relationships with other physicians through sharing patients in Yinzhou, China, and these relationships had similar rates of persistence to studies conducted in developed countries, which indicated that findings of social network analyses conducted in developed countries still hold value in developing countries.

INTRODUCTION

The translation and diffusion of knowledge inevitably affect physicians' prescribing behaviours, especially among physicians providing care to shared patients, with

STRENGTHS AND LIMITATIONS OF THIS STUDY

⇒ We applied social network analysis methods to measure the structure and persistence of physician relationships in hypertension management.
⇒ We used a well-established regional electronic health information system to capture a comprehensive view of physician patient-sharing relationships across different levels of healthcare institutions.
⇒ The actual patient flow and dynamics of physician relationships were unable to be observed.
⇒ The association between the persistence of physician relationships and patient health outcomes was unable to be examined.
⇒ The results were subjected to unmeasured confounding bias due to limited data availability.

implications for patient health and healthcare utilisation.[1] An increasing number of research have used social network as a tool to understand patient-sharing relationships of healthcare professionals.[2 3] Such analyses can deepen understandings of the influences of knowledge exchange, either formal or informal, on the clinical practice of healthcare providers and identify pathways to improved quality of care and efficient use of healthcare resources.[4 5]

Previous studies have explored the impact of social networks on the prevention and control of infectious diseases, including tuberculosis and malaria, and on knowledge diffusion in managing non-communicable diseases (NCDs) such as diabetes and hypertension.[3 6–9] Patient-sharing networks among physicians signal formal and informal exchange of knowledge and information while providing care and can help identify and understand problems in medication adherence and therapeutic inertia, both of which are essential to managing NCDs.[10–17] Published studies exploring patient-sharing networks were mainly from developed countries, which found that network-based interventions are effective methods to reduce

healthcare costs and improve the quality of healthcare services.[18–22] These studies have reported that dispersed physician network connection contributed to fragmentation of care and increased costs,[18] while the intensive connections improved quality of care and clinical outcomes.[20–22] The persistence (also known as stability, referring to the continuation of relationships from the previous year into the next) and strength (the number of shared patients between two physicians) of the patient-sharing relationships have been identified as important metrics in network-based interventions.[23–25] Persistent patient-sharing relationships could enable physicians to foster trusting relationships with one another and help to create new referral loops and are thus facilitative to information exchange and coordinating care, which has been interpreted through theories of *diffusion of innovation* or *social contagion*.[23 26 27] Studies have found that many factors might affect the persistence ratio of patient-sharing relationships, including tie characteristics, physician specialty, strength and when such relationships occurred.[18 24 28] However, patient-sharing relationships and the effect they can exert on provider practices can vary across regions with differently structured healthcare systems. It is uncertain if examining these relationships could be a viable tool in studying health services in developing countries and how these relationships can vary from developed countries and regions.[24 27 29 30]

Few studies in low- and middle-income countries have used network analysis to understand professional communication among healthcare providers. Before developing network-based interventions, we need to first understand the structure and persistence of physicians' patient-sharing networks in developing countries and identify influencing factors and their mechanism of action.[31] In China, hypertension is one of the most prevalent NCDs, with a high prevalence of 44.7% among adults aged 35–75 years and generally poorly managed.[32] The management and control of hypertension typically requires collaboration across different healthcare institutions and healthcare providers, especially between various healthcare levels.[33 34] Improved hypertension control has been reported in the well-connected physician professional environment,[35–38] underscoring the significance of promoting the physician's relationship in hypertension management. The patient-sharing network models were widely applied and validated methods to depict and measure these relationships among physicians in prior research.[39 40] Given the knowledge gap in structure and persistence of physicians' relationships in China, we conducted a social network analysis to describe the persistence of patient-sharing relationships of physicians managing patients with hypertension and measure the association between strength and persistence of physicians' relationships in China, for providing insights for achieving better hypertension care coordination and disease control.

METHODS

Study design

In line with previous studies, the patient-sharing relationship between physicians (ie, two or more physicians providing care to the same patients) was recorded in and identified through reviewing records of outpatient visits, with the number of the shared patients between physicians representing the strength of the relationship.[24] Patient-sharing represents exchanges of knowledge among physicians and could therefore be used to assess physicians' coordination, a clear target for cost-saving and improving the quality of medical care.[41 42] To understand the network structure and factors associating with patient-sharing relationships in Yinzhou district of Ningbo, a coastal city in south-east China, we built a theoretical model of Chinese physicians' professional network based on patient-sharing relationships.

Data sources

We extracted data from the Yinzhou Health Information System (YHIS), which was established by the local health department in 2005. Since its inception, the database has achieved registration of over 98% of permanent residents (approximately 1.3 million) and all healthcare providers (5.8 thousand) in Yinzhou.[43 44] The system collects and manages electronic medical records of residents and covered data including general characteristics, prescription and outpatient visit records. All information stored in the system has been de-identified to safeguard patient privacy; thus, the requirement of informed consent was exempted according to the national legislation and the institutional requirements. Ethical approval was obtained from the Peking University Institution Review Board (IRB00001052-22052).

Study population

We extracted all outpatient records from YHIS. Inclusion criteria were: (1) the patient was diagnosed with hypertension, shown by the corresponding International Classification of Diseases, Tenth Revision codes (I10, I11, I12, I13 and I15); (2) the patient's hypertension diagnosis was between 1 January 1 2010 and 31 December 2018; and (3) Primary Care Physicians (PCPs) or specialists working in secondary and tertiary hospitals who treated adult hypertension patients (≥18 years old). Our exclusion criteria were: (1) outpatient records generated from patients not residing in Yinzhou district and (2) patient-sharing relationships not occurring in the same year (eg, a physician provided care to this patient in a year while the other physician only provided care to this patient in the other year).

Network construction

We constructed physician networks by identifying relationships between physicians if one patient had visited both of them within the same year. Specifically, we first constructed the bipartite network composed of physician-patient connections by extracting the outpatient visit
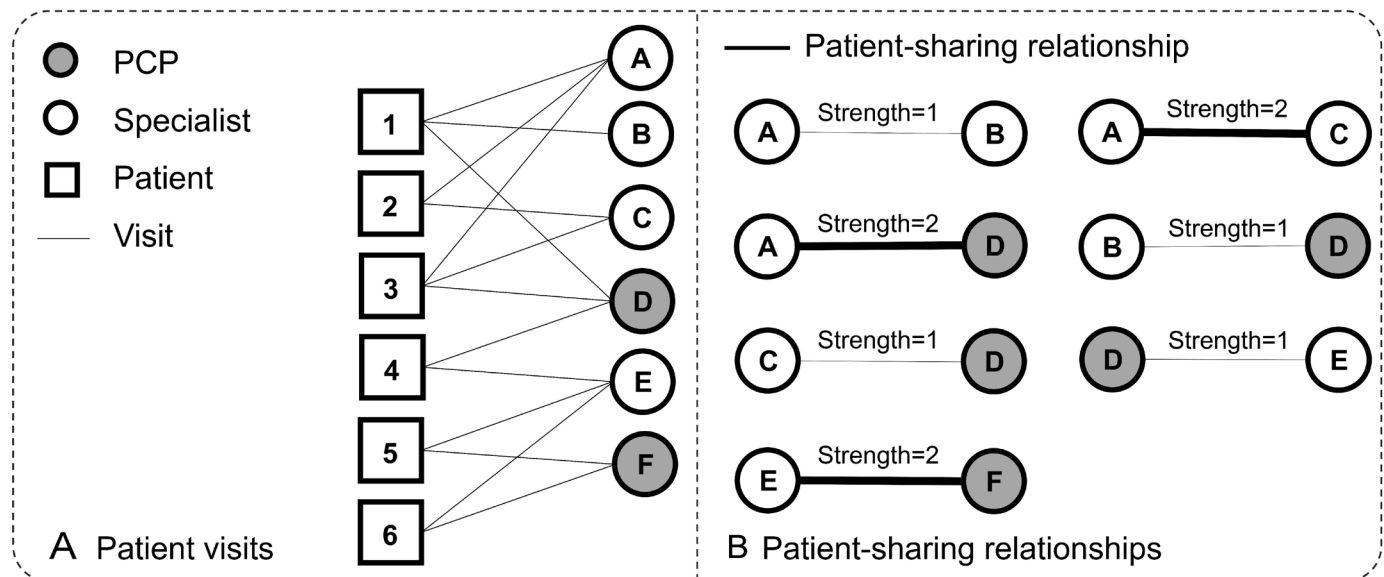
Figure 1 Schematic diagram of the patient-sharing relationships. Node, physicians in the network; tie, the connections between physicians in patients-sharing relationships; strength, the weight of the ties between the two nodes refers to the number in patients-sharing relationships. PCP, primary care physicians.

records within a year and generated the adjacency matrix of bipartite network (figure 1A).[40] Then, we constructed the physician-physician unipartite network by multiplying the adjacency matrix of bipartite network with its transpose.[45] The elements in the matrix of unimodal network were the number of patients shared between two physicians, which represented the strength of their relationship (figure 1B). The threshold of the network was defined as the minimum strength of patient-sharing relationships needed to form a physician connection. For instance, 'threshold=2' indicated that two physicians would need to share at least two patients to be regarded as in a network. In the analysis, we did not apply a fixed threshold; instead, we tested multiple thresholds from 1 to 9 (the range was determined based on previous reports and validation) to identify stable patient-sharing relationships and reduce the impact of incidental connections that have a lower probability of knowledge exchange.[27 39]

Measurements and covariates

The main outcome of the analysis was the persistence of the physician-physician connections in the patient-sharing network, defined as the physician relationship in a given year continued to exist in the following year.[23] We used the persistence ratio, which refers to the proportion of remained relationships, to measure the degree of persistence. For instance, if 10 pairs of patient-sharing relationships were observed in 2008 and eight of them persisted to 2009, the 1year- persistence ratio would be 80%. Connections that persisted for two or more years were seen as long-term relationships that could diffuse knowledge more intensely and thus have a larger effect on the prescribing behaviours of the physicians involved.[29]

Many factors have been reported in association with the persistence of patient-sharing relationships.[24 29] We included the tie characteristics, physician specialty,

strength of the relationship and when such relationships occurred as covariates in our analysis, based on previous literature, theoretical framework of diffusion and data availability. The tie characteristic was a binary variable reflecting whether the patient-sharing relationship happened within one or across multiple hospitals. A patient-sharing relationship was also classified according to specialties involved and assigned to a category of the following: 'PCPs-PCPs', 'PCPs-Specialists' and 'Specialists-Specialists'. The year when the patient-sharing relationship occurred was defined as the year when the outpatient visit (signalling a patient-sharing relationship) happened. Based on previous literature, we assumed that the knowledge translation and diffusion across years and hospitals could promote coordination of PCPs and specialists and subsequently improve healthcare system efficiency. Detailed variable selection and definition are reported in table 1.

Statistical analysis

We conducted logistic regression to analyse factors associating with the persistence of patient-sharing relationships, with the 95% CI and P value reported for each OR.[46] We applied logistic regression rather than exponential random graph models as we primarily focused on assessing the strength and persistence of the physicians' relationships already identified, rather than examining the formation of the network. Strength $\in$ [1, 3), "Tie characteristics" = "no", "Physician specialty" = "PCP-PCP", and the year of 2010 were set as reference group in the regression. To visualise the structure of the patient-sharing network, we chose the Fruchterman–Reingold algorithm, a spring-embedder method, to present the physician network, with two physicians having stronger patient-sharing relationships lying closer in the illustration.[40 47] In the analysis of the persistence ratio of

Table 1 Variable selection and definition in the analysis of patient-sharing relationship in Yinzhou

Variable	Definition	Meaning
Persistence ratio	The proportion of the patient-sharing relationships in a given year that continue to exist in the following year.	Reflecting long-term relationships across years, the professional knowledge may diffuse through the network and have an effect on the physicians' prescription behaviour.
Relationship strength	The number of sharing patients between physicians.	Representing a more stable patient-sharing relationship, higher persistence ratio and long-term patient-sharing relationships have positive effects on knowledge diffusion in the network.
Hospital characteristics	Whether the related physicians of the patient-sharing relationship are from the same hospital.	The patient-sharing relationships among different physician specialties are conducive to representing whether knowledge diffusion in a larger geographical area is helpful to the update of clinical treatment experience.
Physician specialty	The specialty of the related physicians in a patient-sharing relationship.	Regions with higher persistent ties tended to have lower rates of emergency medical visits, and regions where PCPs had more physician connections were more likely to have higher emergency medical visits.
Relationship occurrence year	The year of the visit when the physician-sharing relationship happened.	The impact of occurrence year on the patient-sharing relationships could help to understand the trend, and other influencing factors on the patient-sharing relationships (eg, policy factors) could help to explore and assess the network-based interventions.

patient-sharing relationships, we conducted a sensitivity analysis based on thresholds and years of persistence of patient-sharing relationships; in the analysis of the factors of patient-sharing relationships, we conducted sensitivity analyses on the 1-, 2- and 3-year persistence to test the robustness of the findings. All analyses were performed using R 4.0.4, and a two-sided P value <0.05 was considered statistically significant.

Patient and public involvement
Patients and the public were not involved in this study.

RESULTS
Study sample
Our final sample included 27 267 hypertensive patients and 3916 physicians from 42 public healthcare facilities. The median and range of the number of patients, physicians, and public healthcare facilities each year are described in table 2. Overall, the median of physicians included according to the inclusion criteria was 1572 (range 1264–2106) from 2010 to 2018, including 68.1% (54.5%–77.5%) PCPs and 31.9% (22.5–45.5%) specialists. The detailed number of samples from 2010 to 2018 was reported in online supplemental etable 1.

Structure of patient-sharing network
The patient-sharing network is visualised in online supplemental efigure 1. Overall, the median number of patient-sharing relationships (ie, physician ties) was 67 203 (range 36 543–89 463) from 2010 to 2018, while the median number of relationships per physician was 41.7 (28.9–44.4, table 3 and online supplemental etable 2). Among these ties, 70.8% (67.3%–74.1%) happened between physicians from different healthcare institutions (HCIs), while others were between physicians from

the same HCI. The majority (55.1% (47.9%–60.9%)) of observed connections were between PCPs, 34.0% (30.9%–38.1%) were between PCPs and specialists and 9.9% (8.2%–14.4%) were between specialists. Most (68.9% (67.9%–75.3%)) observed connections had a strength $\in [1, 3)$ (ie, the two physicians had one or two tie(s)); only 10.7% (9.5%–11.4%), 4.7% (3.6%–5.3%), and 2.7% (2.0%–3.0%) had a strength $\in [3, 5)$ (ie, the two physicians had three or four ties), strength $\in [5, 7)$ and strength $\in [7, 9)$. There are many patient-sharing relationships that had a strength ≥ 9 (12.5% (9.5, 13.1)). The network characteristics at different thresholds were reported in the online supplemental etable 3. Overall, the network diameter from 2010 to 2018 ranged from 6 to 9 for thresholds from 1 to 9; the network density ranged

Table 2 Number of sampled patient and physicians constructed physician network for medication therapy management of hypertensive patients in Yinzhou from 2010 to 2018

Number of samples	Median	Range
Number of patients	129 021	(77 063, 181 997)
Number of hospitals		
Total	29	(25, 41)
Primary care facilities	25	(22, 33)
Secondary hospitals	1	(1, 3)
Tertiary hospitals	3	(2, 5)
Number of physicians		
Total	1572	(1264, 2106)
Primary care facilities	1070	(948, 1287)
Secondary hospitals	77	(54, 153)
Tertiary hospitals	440	(230, 703)

Table 3 Characteristics of patient-sharing relationships for medication therapy management of hypertensive patients in Yinzhou from 2010 to 2018

Number of observed connections	Median	Range
Total	67 203	(36 543, 89 463)
Hospital		
Not in the same hospital	47 896	(24587, 64 089)
In the same hospital	19 307	(11 956, 25 374)
Physician specialty		
PCP-PCP	37 182	(22 272, 47 477)
PCP-Specialist	22 877	(11 285, 30 093)
Specialist-Specialist	6534	(2986, 11 893)
Strength of connections		
[1,3)	46 330	(24 871, 67 378)
[3,5)	7073	(4101, 8484)
[5,7)	3099	(1937, 3292)
[7,9)	1817	(1054, 2002)
≥9	8339	(4580, 9187)

PCP, primary care physicians.

from 0.18 to 0.55 for thresholds from 1 to 9; the clustering coefficient ranged from 0.33 to 0.45 for thresholds from 1 to 9.

Persistence of patient-sharing network

Changes in the persistence of patient-sharing relationships for different network thresholds are shown in figure 2. When the threshold equalled 1, relationships seemed random and displayed trends vastly different from those shown when other thresholds were applied. When the threshold was set at 3 (ie, only patient-sharing relationships with strength ≥ 3 were retained), the physician network demonstrated a gradually downward trend as compared with when the threshold was set at 1. Patient-sharing relationships showed similar patterns when the threshold was set at 3, 5, 7 or 9, with at least 80% of the relationships persisting after 1 year (threshold=3, 81.8%; threshold=5, 85.8%; threshold=7, 86.9%; and threshold=9, 87.4%) and at least 60% of the relationships persisting after 3 years (threshold=3, 60.4%; threshold=5, 64.4%; threshold=7, 66.1%; and threshold=9, 66.5%).

Factors associating with the persistence of patient-sharing network

Results of the logistic analysis of the factors associating with the persistence of patient-sharing relationships are shown in table 4. We found the increase of strength of the relationships was associating with the increase in persistence of the relationships. Compared with the relationships that had a strength ∈ [1, 3), OR was 3.987 (95% CI 3.896 to 4.08); for relationships with a strength ∈ [3, 5) was 3.987 (95% CI 3.896 to 4.08); 6.379 (95% CI 6.147 to 6.626) for relationships with strength ∈ [5, 7); and 8.373 (95% CI 7.941 to 8.829) for relationships with strength ∈ [7, 9). Physicians from the same HCI were more likely to form connections that persisted for at least 1 year compared with physicians from different HCIs (OR=1.510, 95% CI 1.480 to 1.540). PCP-Specialist relationships and Specialist-Specialist relationships had lower rates of 1-year persistence compared with the PCP-PCP relationships (OR<1, p<0.001).

Sensitivity analysis of patient-sharing networks

We conducted a sensitivity analysis using 2-year and 3-year ties. Results of the sensitivity analysis confirmed that the strength of the relationship, tie characteristics and physician specialty were important factors associating with the persistence of physician's patient-sharing relationships (table 4).

DISCUSSION

This study provides insights into how frequently physicians in China fostered relationships with each other through delivering care to a shared patient and how strong and persistent these relationships were. We found that over 80% of physician relationships formed through sharing patients persisted over a year, and 60% of these relationships persisted over 3 years, a result comparable to results from developed countries.[29] The strength of the relationship, tie characteristics and physician specialty were important factors associating with the persistence of the physician's patient-sharing relationships. To our knowledge, this study is the first to describe the structure and influencing factors of the patient-sharing network among physicians engaged in the management of NCDs in a developing country. These findings suggest that physicians' patient-sharing networks can serve as a stable and viable target for future studies or interventions to promote care coordination and knowledge diffusion in China.

We observed that physician relationships were more persistent as the relationship threshold increased, which aligned with observations from previous studies.[23 39] This suggests that physicians with more shared patients may be more likely to form a more stable professional relationship and demonstrate greater relationship persistence, thereby exerting profound influence on knowledge diffusion within the network.[24] Enhanced knowledge diffusion and information exchange strengthen the quality and coordination of healthcare services, as evidenced by reduced emergency room visits and lower medical costs for patients treated by physicians' persistent connection.[29 48] This effect may also extend across physicians from different hospitals to produce desirable patient outcomes, including lowered odds of readmissions and adverse events.[39 49–51] Therefore, it is feasible to improve the relationship strength and improve healthcare quality by fostering physicians' professional network and
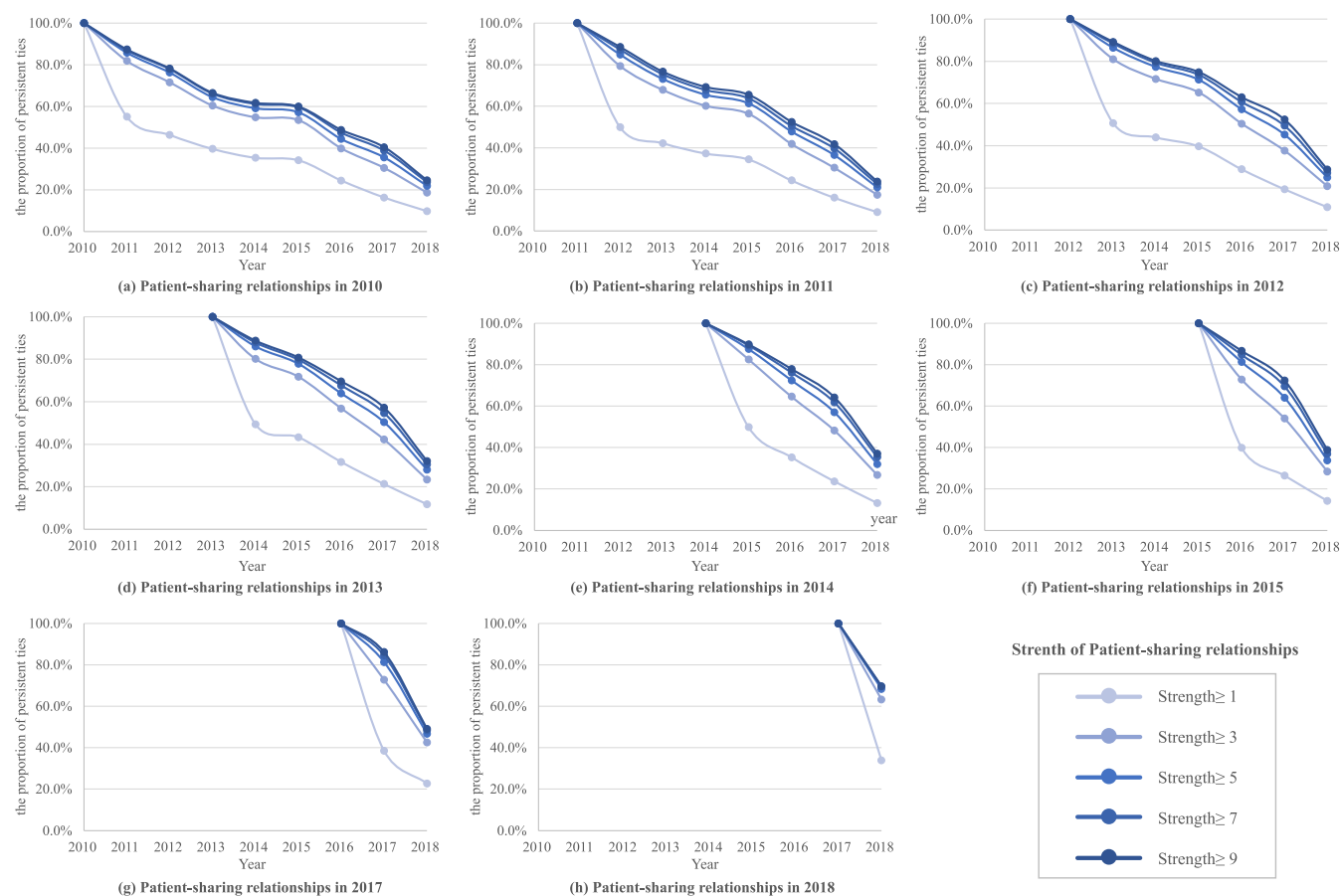
Figure 2 The proportion of persistent ties for patient-sharing relationships for medication therapy management of hypertensive patients in Yinzhou from 2010 to 2018. (A–H) the proportion of persistent ties generated in 2010–2018, respectively.

promoting regular physician communication among providers.

In middle-income countries like China, the burden of cardiovascular diseases was more inequitably distributed than in high-income countries, which is often exacerbated by a severe under-resource of personnel with expertise in and infrastructure supporting the management of cardiovascular diseases.[16] Developing interventions that use patient-sharing networks already present in physicians' day-to-day practices and that strengthen the hierarchical medical system can be an effective and cost-saving approach to influence physicians' behaviours, improve their coordination and promote patient outcomes. As patient-sharing relationships formed among physicians of different HCIs can diffuse knowledge and influence their prescribing behaviour, they can be used to promote the optimisation of patient treatment plans to reduce patient burden and improve clinical outcomes in managing NCDs like hypertension.[13 18 48]

Our study confirmed that physicians both from primary care facilities were more likely to form and keep patient-sharing relationships, a result similar to a previous study.[52]

The finding implied that the less cohesive care coordination across different levels of facilities in the Chinese healthcare system[53] may lead to suboptimal care continuity and disease control.[54] These relationships among physicians across different levels of HCIs and specialties could lend insight into the barriers and promoters of an efficient healthcare system.[55] They are conducive to the knowledge diffusion beyond one single HCI, which has the potential to spread clinical treatment experience to improve quality of care in primary healthcare facilities, where physicians normally have less clinical capacity.[18] This is supported by a previous study which found that a high value of network statistics, reflecting global connectivity, is beneficial to medical cost savings.[30] In contrast, hospitals with greater dispersion were associated with greater rates of readmission and lower rates of emergency department throughput.[30 56] Patient-sharing relationships among physicians can be a clear target to develop network-based interventions to curb these unfavourable outcomes.

The Chinese government launched a hierarchical medical system policy in 2014, aiming to alter patients'

Table 4 Logistic regression of persistent ties for patient-sharing relationships for medication therapy management of hypertensive patients in Yinzhou from 2010 to 2018

	One-year persistent ties		Two-year persistent ties		Three-year persistent ties	
	OR	95% CI	OR	95% CI	OR	95% CI
Strength						
(1,3)	Reference	–	Reference	–	Reference	–
(3,5)	3.987***	(3.896 to 4.08)	3.203***	(3.13 to 3.274)	2.790***	(2.724 to 2.858)
(5,7)	6.379***	(6.147 to 6.626)	4.716***	(4.563 to 4.874)	3.796***	(3.669 to 3.924)
(7,9)	8.373***	(7.941 to 8.829)	6.019***	(5.755 to 6.29)	4.614***	(4.424 to 4.816)
≥9	11.965***	(11.6 to 12.354)	8.290***	(8.077 to 8.508)	6.184***	(6.032 to 6.341)
Hospital characteristics						
Not in the same hospital	Reference	–	Reference	–	Reference	–
Same hospital	1.510***	(1.48 to 1.54)	1.402***	(1.373 to 1.43)	1.358***	(1.33 to 1.385)
Physician specialty						
PCP-PCP	Reference	–	Reference	–	Reference	–
PCP-Specialist	0.876***	(0.862 to 0.891)	0.693***	(0.68 to 0.705)	0.555***	(0.544 to 0.567)
Specialist-Specialist	0.566***	(0.55 to 0.582)	0.463***	(0.45 to 0.476)	0.384***	(0.373 to 0.396)
Year						
2010	Reference	–	Reference	–	Reference	–
2011	0.803***	(0.779 to 0.826)	0.854***	(0.829 to 0.879)	0.937***	(0.909 to 0.965)
2012	0.826***	(0.803 to 0.85)	0.914***	(0.888 to 0.94)	1.035***	(1.005 to 1.065)
2013	0.791***	(0.768 to 0.813)	0.905***	(0.88 to 0.931)	0.696***	(0.676 to 0.716)
2014	0.811***	(0.789 to 0.834)	0.599***	(0.583 to 0.617)	0.429***	(0.416 to 0.442)
2015	0.510***	(0.496 to 0.524)	0.379***	(0.368 to 0.39)	0.221***	(0.214 to 0.228)

One-year persistent ties represent ties that generating in 1 year and persist in the next year, 2 year represents persisting in next 2 years and 3 year represents persisting in next 3 years; when considering the 3year- persistent ties, the ties generating in 2015 that persists in 2018, therefore, the year of 2016, 2017 and 2018 were unobservable.
***p<0.001, **p<0.01, *p<0.05.
PCP, primary care physicians.

healthcare-seeking behaviours. After its implementation, most patients are expected to first visit a primary care facility, which ideally should be the same facility to ensure consistency in care. This redirection of patient flow to primary care facilities may cause PCPs to share patients more frequently, and thus more physicians could have more possibility to form stronger patient-sharing relationships.[54] We also found that the proportion of patient-sharing relationships formed between physicians practising at the same HCI was lower than that reported in developed countries.[40 57 58] This may imply that HCIs in China have not established a harmonised patient referral system and thus patients frequently move between HCIs when certain needs remain unmet, which helped to form physician connections across HCIs.[59] A previous study has found that PCPs have a central role in managing chronic diseases, and a hierarchical medical system can leverage the management of NCDs.[42] Another study has confirmed the increased persistence of patient-sharing relationships across different healthcare levels since 2015, when the hierarchical medical system policy was implemented in China, which is attributed to the policy's promotion of primary care physician's centrality in disease management.[54]

There are several limitations to this study. First, we established the social network of physicians based on a database from a single district in China; thus, our result may not be generalised to other areas in China with different physician network structures. Additionally, we were unable to observe the actual patient flow and the dynamics of these relationships from the retrospective data. A fuller landscape of the impact of knowledge diffusion through these relationships on physicians' prescribing behaviours may only be gained through conducting qualitative studies in the future. Second, we limited the disease area to hypertension to represent the characteristics of the patient-sharing network of physicians managing NCDs. However, physician networks may be affected by differences in chronic diseases, such as patient characteristics, which were unable to be incorporated in this study. For instance, the differences in severity of the disease or comorbidities may lead to distinct patient visiting patterns; thus, our results should be interpreted within the specific context. Third, we are only constructing the network using the 1year time frame to identify physicians' relationships. Though there was a study observing that shorter time frames do not significantly affect the results,[60] it is possible that the results could be different if we change the time frames in our setting. Future research should consider constructing networks over different time frames as data permit. Fourth, our association analysis may be subject to unmeasured confounding bias since we failed to include additional physician factors potentially associated with the persistence. For instance, factors such as physicians' practising department, years in practice or professional title were not included, whereas it is possible that physicians may be more likely to establish connections with others who shared similar characteristics.[61] Future

research should consider incorporating relevant factors more comprehensively or applying methods such as instrumental variables to effectively control for potential confounding. Last, we have not examined the relationship between the persistence of physician relationships and patient health outcomes, which holds greater clinical and policy relevance. Future research should focus on this topic to offer novel insights for healthcare policy and practice, especially on leveraging physicians' social networks to improve healthcare delivery.

Conclusions

We found that physicians frequently formed relationships with other physicians through sharing patients in Yinzhou, China. These relationships showed similar rates of persistence to studies conducted in developed countries, where network-based interventions have been proven effective in curbing some problems in healthcare delivery and patient outcomes. Future research and interventions to promote care coordination and knowledge diffusion can leverage these naturally occurring relationships and seek to understand mechanisms through which they can exert influences on healthcare providers' practices and coordination with one another.

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