ORIGINAL ARTICLE

Relationships between road-distance to primary care facilities and ischemic heart disease and stroke mortality in Hokkaido, Japan: A Bayesian hierarchical approach to ecological count data

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Abstract

Objective: Poor access to a primary care physician may lead to poor control of risk factors for disease. This study investigated whether geographic access to a primary care physician was related to ischemic heart disease and stroke mortality.

Methods: Road-distances from the centroids of the basic unit blocks of the 2010 Japanese Census to the nearest primary care facilities in Hokkaido, northern Japan, were measured using geographic information system (GIS) software. Next, block population-weighted mean road-distances to primary care facilities in all municipalities were calculated. The numbers of deaths from ischemic heart disease and stroke were obtained from the Vital Statistics Bureau. A Bayesian spatial conditional autoregressive (CAR) model was used to analyze relative risk (RR) by road-distance with the numbers of physicians in the municipality included as a covariate.

Results: Relative risk (per 1 kilometer increased) of death from ischemic heart disease to road-distance to the nearest primary care facility was not significantly higher in men (1.108: 95% credible interval [CI] 0.999-1.037) and women (1.023: 95% CI 1.000-1.046). However, RR of death from stroke was significantly higher in men (1.019: 95% CI 1.005-1.032) and women (1.019: 95% CI 1.006-1.033).

Conclusion: Longer road-distance to a primary care facility may increase the risk of stroke mortality.

KEYWORDS
Bayesian spatial conditional autoregressive model, geographic information system (GIS), ischemic heart disease, road-distance, stroke

1 | INTRODUCTION

The disproportionate distribution of health care workers is a serious global problem. Even high-income countries experience shortages in remote and rural areas.[1] Rural populations in developed countries such as Australia and USA have poorer health outcomes than metropolitan populations,[2,3] and in Germany, they have limited access to a general practitioner (GP).[4]

General practitioners play an important role in disease prevention and health promotion for the general population.[5] In Japan, all citizens

are covered by the national health insurance system, and patients can freely choose between going to a physician's office or a larger general hospital because the health care system has no officially defined general physicians or gatekeepers.[6] However, the importance of enabling functional differentiation and the establishment of referral networks in clinics and hospitals has been recognized.[7] In 1996, the Japanese Ministry of Health, Labour and Welfare (MHLW) introduced a new health care policy to restrict access to large hospitals (200 beds or more) to be able to facilitate the functional differentiation between office-based and hospital-based medical care. Consequently, patients who go to a large hospital without a referral from a primary care physician now have to pay a supplementary charge.

The MHLW and the Japan Medical Association have stated that the number of primary care physicians who diagnose and treat common illnesses or medical conditions and refer patients to hospitals with specialists should be increased.[8,9] As a result, the Japanese Medical Association has established continuing medical education program for doctors working in primary care who currently function as "family doctors."[10] Thus, small community-based clinics in Japan function as a primary care facility, even though Japan has no officially defined GP system.

Primary care physicians have been shown to be pivotal in the control of risk factors for coronary heart disease and stroke,[11,12] and higher primary care physician density is related to lower mortality[13,14] and lower obesity.[15] Geographic information system (GIS) are widely used to evaluate access to health care facilities, and spatial access disparity evaluated using GIS has been reported.[4,16] However, to our knowledge, the relationship between primary care physician access disparity and health outcomes has not been fully elucidated. Therefore, the aim of this study was to investigate whether primary care physician access evaluated by GIS was related to ischemic heart disease and stroke mortality using ecological data analysis.

2 | MATERIALS AND METHODS

This is an ecological study which took place in Hokkaido, northern Japan. Hokkaido is Japan's second largest island, its largest prefecture (total area: 83 450 km^2), and the prefecture with the lowest population density (total population: 5.38 million; density: 64.5/km^2). Hokkaido has a cold climate, with a long period of snow cover in winter.

Primary care clinics were defined as medical institutions with less than 20 inpatient beds,[17] whose specialty included internal medicine and were listed by Hokkaido prefecture government (on April 1, 2015).[18] Of 2133 institutions, we excluded those facilities which were not primary care facilities for the general public (eg,: clinics for the Self-Defense Forces, in universities, in public health centers, in welfare institutions for elderly people, and out-of-hours emergency centers); those which were closed between 2010 and 2014; those open less than 5 days a week, and those specializing in home visits only. This resulted in 1363 clinics being selected. Moreover, of the 188 municipalities in Hokkaido, 29 had none of the above-defined primary care clinics. Therefore, we allocated municipal center hospitals to 28 municipalities. However, one municipality (Shimukappu)

had no such hospital (only clinics open less than 5 days a week). One further municipality (Esahsi [Soya]) had one primary care clinic, but it was located in a town in the Utanobori distinct which was merged into Esashi at 2006 and had a smaller population. Therefore, we allocated a center hospital at Esashi as an additional primary care faculty. Finally, 1392 institutions were defined as primary care facilities.

Road-distances from the centroids of the basic unit blocks (cho-cho-aza) of the 2010 Japanese Census to the nearest primary care facilities were measured by network analysis (GIS Software: ArcGIS 10.3 Network Analyst, ESRI and road data: ArcGIS data collection "Network of road 2014," ESRI). Next, block population-weighted mean road-distances to primary care facilities in all municipals were calculated as follow:

$$\frac{\sum \{(\text{number of population in the block}) \times (\text{road-distances of the block})\}}{\text{number of the population of the municipal}}$$

The numbers of deaths from ischemic heart disease (I20-I25 of ICD-10) and stroke (I60-I69 of ICD-10) were obtained from the Vital Statistics Bureau of Japan,[19] and five-year averages (2010-2014) for each municipality and for Japan overall were calculated. To calculate expected number of deaths, the total Japanese population was used as the reference population, and five-year average population (2010-2014) stratified by five-year age groups was calculated based on the 2010 Census and population estimates (2011-2014).[20] Gender and the five-year age group stratified population (2010-2014) for each municipality was calculated based on the 2010 Census and population of the basic resident register (2011-2014).[21]

The number of physicians per population was used as a potential confounder. The three-year average number of physicians per municipality population was calculated based on the Survey of Physicians, Dentists, and Pharmacists (2010, 2012, 2014).[22]

2.1 | Statistical analysis

We fitted a random-effect Poisson model allowing for spatial correlation, using the conditional autoregressive (CAR) prior.[23,24] Men and women were analyzed separately. All models were implemented using the Bayesian Gibbs Markov Chain Monte Carlo (MCMC) algorithm with the OpenBUGS version 2.3.2 software.

We assumed that O_i was a realization of the independent Poisson random variable, where μ_i denotes the number of deaths from ischemic heart disease or stroke referring to the i-th municipality, and E_i denotes the expected number of deaths which were calculated after stratification for gender and the five-year age group as mentioned above. The model can be expressed as follows (where ~ denotes "is distributed"):

$$O_i \sim \text{Poisson}(\mu_i)$$

$$\log \mu_i = \log E_i + \alpha + \beta X_i + b_i + h_i$$

$$h_i \sim N(0, \tau_h)$$

$$b_i \mid b_{i \neq j} \sim N\left(\bar{b}_i, \frac{\tau_b}{m_i}\right)$$

where α is the intercept, β is a regression coefficient of an independent variable (road-distances, number of physicians, or both [two regression coefficients used] were included)), h_j is a random effect which models the unstructured heterogeneity, b_i is a spatially structured random effect with adjacent neighbors of i, $\bar{b}_i$ the average of the adjacent neighbors of b_i, m_i = number of neighbors in area i, and assigning a vague prior distribution Gamma (0.5, 0.0005) to the unknown variance of hyperparameters h and b. Regression coefficients and 95% credible intervals (CIs) were derived from posterior distributions and converted to relative risks (RRs: per 1 km increased for load-distance; per 10 000 people increased for number of physicians). In Model 1, each explanatory variable was introduced separately, and, in Model 2, both variables were introduced simultaneously. In this Bayesian estimation, As we were not able to obtain direct values, "95% CI did not include 1" was dealt as a significant result.

3 | RESULTS

Table 1 shows the road-distances, numbers of physicians, and standard mortality rates (SMRs) from ischemic heart disease and stroke among the 188 municipalities. Mean road-distance was 3972 meters and ranged from 483 to 24 718 meters. Mean SMRs (ranges) of ischemic heart disease in men, ischemic heart disease in women, stroke in men, and stroke in women were 91.2 (0.0-259.2), 98.1 (0.0-378.9), 99.1 (0.0-256.7), and 96.6 (14.6-191.4), respectively.

Table 2 shows the RR for death from ischemic heart disease. In Model 1, RR (per 1 km increased) for road-distance was significantly higher in women (1.024: 95% CI 1.001-1.047), but not in men (1.019: 95% CI 1.000-1.039). In Model 2, RR (per 1 km increased) for road-distance was not significantly higher in men (1.018: 95% CI 0.999- 1.037) and women (1.023: 95% CI 1.000-1.046).

Table 3 shows the RR for stroke mortality. In Model 1, RR (per 1 km increased) for road-distance was significantly higher in men (1.019: 95% CI 1.005-1.032) and women (1.018: 95% CI 1.005-1.032). In Model 2, RR (per 1 km increased) for road-distance was still significantly higher in men (1.019: 95% CI 1.005-1.032) and women (1.019: 95% CI 1.006-1.033).

4 | DISCUSSION

In our results, 95% CIs of RRs for road-distance and stroke mortality among both men and women did not include 1, respectively, even after the number of physicians was introduced into the models as a potential cofounder, suggesting that risk of death from a stroke was significantly associated with longer road-distance to a primary health care facility. However, for ischemic heart disease, the 95% CI s included 1, suggesting no such statistically significant association.

TABLE 1 Road-distance, number of physician, and outcomes (Number of municipalities = 188)

	Mean	SD	Median	Min	Max
Road-distance (meter)	3972	2955	3246	483	24718
Number of physicians (per 10 000 people)	6.0	5.4	3.1	1.0	22.4
Standardized mortality ratio (SMR)[a]					
Ischemic heart disease (Men)	91.2	35.8	83.7	0.0	259.2
Ischemic heart disease (Women)	98.1	48.5	86.1	0.0	378.9
Stroke (Men)	99.1	32.3	95.8	0.0	256.7
Stroke (Women)	96.6	26.1	93.2	14.6	191.4

[a]The total Japan population was used as the reference population (=100)

TABLE 2 Relative risk for ischemic heart disease mortality

	Model 1		Model 2	
	RR	95% CI	RR	95% CI
Men				
Road-distance to a primary care facility (per 1 km)	1.019	1.000-1.039	1.018	0.999-1.037
Number of physicians (per 10 000 people)	1.013	0.996-1.030	1.012	0.995-1.030
Women				
Road-distance to a primary care facility (per 1 km)	1.024	1.001-1.047	1.023	1.000-1.046
Number of physicians (per 10 000 people)	0.989	0.968-1.010	0.990	0.969-1.012

Model 1 Each variable was introduced separately.
Model 2 Both variables were introduced simultaneously.
RR: relative risk, 95% CI: 95% credible interval

TABLE 3 Relative risk for stroke mortality

	Model 1		Model 2	
	RR	95% CI	RR	95% CI
Men				
Road-distance to a primary care facility (per 1 km)	1.019	1.005-1.032	1.019	1.005-1.032
Number of physicians (per 10 000 people)	1.005	0.993-1.016	1.005	0.994-1.016
Women				
Road-distance to a primary care facility (per 1 km)	1.018	1.005-1.032	1.019	1.006-1.033
Number of physicians (per 10 000 people)	1.012	1.000-1.024	1.012	1.001-1.024

Model 1 Each variable was introduced separately.
Model 2 Both variables were introduced simultaneously.
RR: relative risk, 95% CI: 95% credible interval

We had a point estimate RR of about 1.02 per 1 km, which meant 2% increase in mortality rate per 1 km further road-distance to the primary care facility. Because the annual number of deaths due to stroke and ischemic heart disease (2015) was 4875 and 2697, respectively, a 2% increase would have a considerable impact.

Standardized mortality ratio (SMR) has been widely used to compare regional mortality rates; however, it has several drawbacks. It is an estimation ratio that produces large changes in estimates but small changes in expected values. When a minimum expectation is found, the SMR will be very large, and this SMR is a saturated estimate of RR.[25] Thus, when small regions, such as small villages in this study, are included in an analysis, crude RRs may not be trustworthy. To overcome this problem, a Bayesian spatial model with random effect assigned CAR prioris used when there is a spatial correlation between observations in neighboring regions.[23,24] In this study, we used this model to avoid overestimation of RRs due to overdispersion of small regions.

As the role of primary care physicians play an important role in controlling risk factors for coronary heart disease and stroke,[11,12] we hypothesized that longer road-distance to a primary care physician, which may be linked to poor primary care accessibility, may be a significant risk factor for death from stroke and/or ischemic heart disease. However, our results were only significant for stroke, but not ischemic heart disease. Stroke mortality in Japan is higher than ischemic heart disease mortality, and hypertension is a strong risk factor for stroke,[26] but to a lesser extent for ischemic heart disease.[27] According to a 2014 Japanese Patient Survey,[28] hypertension was the most prevalent risk factor for stroke among major risk factors such as hypertension, diabetes, and dyslipidemia. Thus, we speculated that residents with known risk factors living near a primary care facility may visit the facility regularly and that may be linked to better risk factor control. Conversely, when risk factors for hypertension are not controlled the impact on stroke mortality may be greater.

We introduced one possible confounding variable, namely, number of physicians. In model 2, and among women, it was a significantly higher RR for stroke. In the United States, the relation between higher primary care physician density and lower mortality has been reported.[13,14] Because there are no accurate Japanese statistics on the number of true primary care physicians, we used the number of physicians, with multiple specialties' selection allowed. Therefore, the number of physicians may not reflect actual primary physician density. Furthermore, because patients in Japan can easily visit primary care facilities without making an appointment in advance, physician density may not truly reflect accessibility. However, the reason for a significantly higher risk of death from stroke among women is unknown.

To analyze accessibility to medical facilities, a straight-line was used.[29,30] However, recently, and especially in high-income countries, road-distance and drive time have also been analyzed using GIS software with road network data.[31] Drive time may be suitable for medical emergencies because the patient is almost always transferred to hospitals by car, but in a primary care setting,[32] access measures include walking, bicycle, car, bus, and train. Therefore, road-distance was selected in this study because drive time reflects only transportation by car and does not include obstacles such as rivers, mountains, and valleys. A recent German study reported accessibility to GPs by public transport.[4] Unfortunately, we did not have such access to public transportation data, but further studies are needed to evaluate more detailed accessibility.

This study has several limitations that need to be mentioned. Firstly, As this was an ecological study which did not have any data on individuals and could not do fully adjust for potential confounding factors. Consequently, we are unable to infer a cause-effect relationship, although we used a Bayesian CAR model, taking spatial correlation into consideration. Secondly, we speculated that poor accessibility to a primary care physician was linked to poor risk factor control. However, we had no concrete data on risk factor control, such as blood pressure. Third, we used the centroid of the basic unit block (cho-cho-aza) to calculate the distance to the primary care facility. However, this distance may vary in populated areas and therefore result in misclassification bias. That may cause a bias in the accuracy of the distances. Forth, access to hospitals treating cardiovascular diseases or strokes, which also may have affected mortality outcomes, was not included in the models. Fifth, Hokkaido has much snow in winter, and the amount of snowfall varies greatly across the island. However, snow removal is carried out adequately in each area, and transfer times to hospitals in winter are almost the same as in other seasons. Finally, as the data were limited to one prefecture in Japan, the ability to generalize results to a larger population may be limited.

In conclusion, longer road-distance to primary care facilities may increase the risk of stroke mortality. From the point of view of equity, access to primary care physicians, especially in rural areas, should be improved.

CONFLICT OF INTEREST

The authors have stated explicitly that there are no conflict of interest in connection with this article.

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