Manuscript Type: Original Research Article

Title of Manuscript: Relationship between accessibility and resources to treat acute ischemic stroke. Hokkaido, Japan: Analysis of inequality and coverage using geographic information systems

Keywords: health services accessibility, spatial analysis, geographic information system, emergency medical services

Abstract:

Objectives: This study aimed to clarify the relationship between the institution and resident with respect to accessibility to acute ischemic stroke (AIS) treatment in Hokkaido and to propose new methodology monitoring for accessibility to healthcare resources.

Methods: This study involves the use of geographic information system (GIS) network analysis. We established hospital/clinic with one of the following conditions as resources for AIS treatment: (1) medical facility practicing AIS treatment, (2) having computed tomography (CT) equipment, (3) having angiography equipment, and (4) having AIS specialists (neurosurgeons). We evaluated the coverage of population resources using transport time between ambulance departure and arrival at the healthcare facility. Furthermore, we compared the population coverage rate using available resources and calculated a Gini coefficient to analyze its relation with inequality. Empirical analysis was performed, and public database for data collection was utilized. We calculated the rate of population coverage with a transport time within 10 minutes as an indicator of accessibility to medical resources by GIS.

Results: The Gini coefficients of practicable facilities, CT, angiography, and neurosurgeons are 0.35, 0.16, 0.18, and 0.30, respectively. The inequality of accessibility differs depending on the resources, and Gini coefficients indicate that hospital/clinic and neurosurgeons were considered to have higher allocation inequalities than CT and angiography.

Conclusions: Combining Gini coefficient and GIS network analysis in accessibility can be useful in quantifying and monitoring variation by region. We propose this combination as a new method for helping the government to make evidence-based healthcare planning.

Main Manuscript

Introduction

Medical systems should facilitate effective functioning of emergency medical services (EMS) by collaborating with medical institutions, thus promoting fairness and equal access of community medical care. Recently, EMS demand is increasing in Japan. The frequency of ambulance calls is increasing annually; in 2007, there were 5,290,236 calls, whereas, in 2017, it increased to 6,342,096 calls (growth rate: 16.6%). Rescue requests due to "sudden illness" accounted for 64.3% of the calls [1]. The rate of EMS calls will increase concurrently with the aging rate in Japan. In 2015, 26.7% of Japan were "aged," and this number is expected to increase to 35.3% in 2040 [2]. Aging will increase the demand for emergency services due to the increase in the incidence of myocardial infarction and stroke [3, 4]. Furthermore, the increasing trend of aging rate varies from region to region; Hokkaido is an area of particular concern [2], as in 2015, the percentage of population aged ≥65 years was 29.1%, and it will increase to 40.7% in 2024 [5].

The Ministry of Health, Labour and Welfare has introduced laws to formulate a medical care plan in each prefecture with the aim of securing a medical provision system that is consistent with the national policy and actual circumstance of each prefecture [6]. Secondary medical service area is defined in this plan and is regarded as a district unit when considering EMS or inpatient medical care systems. Planning and proposal for the distribution of healthcare resources, such as medical institutions, medical equipment, and human resources, are done in secondary medical service areas (SMSA). Medical care planning is done to intensively address important diseases, such as stroke and myocardial infarction in acute diseases, malignant neoplasms and diabetes in chronic diseases, and mental illness. The government of Hokkaido devised the "Hokkaido Medical Plan" commensurate with the geographical conditions of vast land and statistical realities such as population reduction. Previous studies on healthcare resources in Hokkaido have reported a maldistribution of physicians and medical institutions and inequality in access to medical care [7, 8]. In a medical plan, it is necessary to propose countermeasures after identifying and clarifying issues on medical resources and access. However, to the best of our knowledge, no studies have investigated the relationship between healthcare resource inequality and accessibility. Under the current circumstances, the best assessment of how medical resources influence access is to explore a way for equal provision of health services, from the viewpoint of medical providers. To provide medical treatment equally to every resident, it is necessary to analyze accessibility and inequality of medical resource allocation, in the context of different regional needs and supply and demand.

Accessibility to medical services is bound by factors such as region, cost, and resident healthcare literacy [9]. Lesvesque et al. have classified the concepts of accessibility into five categories: “approachability,” “acceptability,” “availability and accommodation,” “affordability,” and “appropriateness” [10]. To secure a provision system for EMS with high equality, “approachability” and “availability” have been emphasized as important factors for treatment delivery. Thus, this is the focus of our study. In particular, we assessed the geographical accessibility of residents to EMS institutions, which correspond to the “approachability” and “availability” categories of Lesvesque’s classification. Quantitative analysis of healthcare provision systems is effective for evidence-based healthcare policies. Some studies have attempted to negotiate appropriate policy proposals by evaluating resource allocation and geographical accessibility [8, 11]. In recent years, governmental administrative organizations have tried to recognize the relationship between geography and health status. A geographic information system (GIS)is a computer-based system for collecting, editing, integrating, visualizing and analyzing spatially referenced data and can be applied to public health informatics and epidemiology [12]. Many studies have evaluated accessibility by calculating the rate of population coverage from a particular healthcare institution using Response time as a boundary for evaluation [13]. Here, Response time is composed of three intervals: (1) Arrival time: time between emergency call and arrival of ambulance, (2) Stay time: time spent by ambulance on site, (3) Transport time (TT): time between ambulance departure from site and arrival at healthcare facility. However, little has been reported on the accessibility to healthcare resources, not only to the physical institution but also to human resources, equipment, and the specialized diagnostic skill to treat acute diseases. This can be attributed to the fact that no methodology has been proposed to evaluate the relationship between resource allocation and accessibility from the perspective of time and distance. Advances in therapeutic technology have provided intravenous recombinant tissue-type plasminogen activator (rt-PA) to treat acute ischemic stroke (AIS). Despite these advances, the AIS care system is not adequate in rural Japan, and these advanced treatment methods require high-quality resources and have thus been concentrated in the urban areas [14]. Therefore, an analysis must consider the relationship between resources and residents for an honest evaluation of accessibility to EMS. Thus, this study aimed to clarify the relationship between an institution and resident with respect to accessibility to AIS treatment and to propose new methodology monitoring for accessibility to healthcare resources.

Methods

Hokkaido has a land mass equal to 22% of Japan, but the population density is the lowest of all 47 prefectures: 68.6 people per square kilometer. It has 21 SMSAs divided into geographical units for medical care planning [Fig.1 (A)]. Fig.1 (B) and (C) display population share and population density by SMSA, showing that Hokkaido's population is concentrated in Sapporo, where the population increase is driving urbanization. It is expected that depopulation will progress in other areas. This change will lead to regional disparities in social infrastructure and economic activity. From the viewpoint of community healthcare, there is a concern that the healthcare system will shrink due to the shortage of human resources in rural areas. Therefore, creating a system that allows equal and appropriate EMS access in Hokkaido is a major issue in the medical system design field. From these reasons, Hokkaido is a high-priority area for the development of emergency medical systems.

This study involves the use of GIS network analysis using characteristics of traffic flow to measure the time it takes for patients or doctors to access healthcare resources by car (ArcGIS Ver10.2; ESRI) [15, 16]. We evaluated the population coverage by using TT as a boundary. Furthermore, we compared the rate of population coverage by resources and calculated Gini coefficient to analyze its relationship with inequality.

Subject and Data Collection

In this study, empirical analysis was performed using a public database without our original survey. The Japanese Statistics Bureau of the Ministry of Internal Affairs and Communications published mesh data of the World Geodetic System, which describes populations by sex and age group based on our national census. The national census is conducted every 5 years, and we used the latest available data from 2015 [17]. The Japan Neurosurgical Society assigns neurology specialists to hospitals [18], and we utilized this information to determine the accessibility of specialists. In addition, we established hospital/clinic with one of the following conditions as resources for AIS treatment: (1) medical facility practicing AIS treatment, (2) having computed tomography (CT) equipment, (3) having angiography equipment, and (4) having AIS specialists (neurosurgeons). This information was collected from the Hokkaido medical function information system database [19], which supplies geographical information of hospitals/clinics in Hokkaido and extractable information of facilities where neurosurgeons practice and where CT/angiography equipment is installed. We extracted information on facilities under the conditions mentioned above to investigate accessibility to resources.

Evaluation of Relationship between Accessibility and Resources

We calculated the rate of population coverage with TT within 10 minutes as an indicator of accessibility to medical resources using Formula (1). The American Heart Association (AHA) announced the "Advanced Cardiovascular Life Support (ACLS) Provider Manual" [20], which shows the concepts of Chain of Stroke (7Ds: detection, dispatch, delivery, door, data, decision, and drug). Accordingly, Prehospital Stroke Life Support (PSLS) is defined as a combination of dispatch, delivery, and door. According to the Canadian Stroke Registry, a delay of 5 minutes in delivery time reduces the probability of t-PA administration by 2%; if treatment initiation in the hospital is delayed by 5 minutes, the probability of malfunctioning increases by 5% [21]. To perform PSLS quickly, rapid patient transport is extremely important. In Japan, the average time of TT is reported to be 8.5 minutes [1]. We adopted "10 minutes" as an acceptable boundary of population coverage with reference to these reports. Assuming rescue operation by ambulance, traffic network analysis was performed using the "Arc GIS data collection road network in Hokkaido 2012." When calculating the size of population within a TT boundary, we assumed that rescue operation by ambulance would obey the speed limit by law.

Furthermore, we calculated the Gini coefficient to assess the regional deviation in patients' accessibility and drew a Lorentz curve onto a coordinate plot with the cumulative medical resource count in each area from the lowest ranking on the vertical (Y) axis and the cumulative population on the horizontal (X) axis. Gini coefficient was defined as the area between the Lorentz curve and the line of perfect equality, divided by the area of the triangle below the line of equality [8]. The value of the Gini coefficient ranges from 0, which indicates complete equality in the distribution, to 1, which indicates complete inequality. The Gini coefficient is calculated as twice the area enclosed by the Lorenz curve and the equality line. In the present study, the Lorenz curve is described by the cumulative percentage of the population within a 10-minute TT.

In Formula (2), where G is the Gini coefficient, n is the number of SMSAs, xi is the cumulative percentage of the ratio of the total population of SMSAs i, and yi is the cumulative percentage of the ratio of the population within the 10-minute TT. A high Gini coefficient indicates a large deviation in the allocation of medical resources. Gini coefficient and Lorenz curve were calculated for the deviation in the medical resources.

Results

The Rate of Population Coverage by SMSAs and Resources

Overall, the rate of population coverage of Hokkaido was 73.3% for hospital/clinics, 84.4% for CT, 77.6% for angiography, and 67.8% for neurosurgeon access (Table 1). The results indicate that accessibility to neurology specialists was the lowest among subject resources; this score represents accessibility. Figure 2 shows the rate of population coverage by SMSAs and resources. Areas in red indicate low coverage, and areas in green indicate high coverage. For example, for hospital/clinic, the Sapporo area has a high score, while the Hidaka area is zero. The coverage rate by resource in each region is shown in Figure 2. These results also show the relationship between practical facilities and each resource.

Calculation of Gini Coefficient

Figure 3 shows the Lorentz curve of practical hospital/clinic, CT, angiography, and neurosurgeon access, with a calculated Gini coefficient of 0.35, 0.16, 0.18, and 0.30, respectively, indicating that inequality of accessibility differs by resource. The Gini coefficient data shows that hospital/clinics and neurosurgeons were considered to have relatively higher allocation inequalities than CT facilities and angiography. The Gini coefficient reflects the allocation inequality in each resource, implicating that facilities and neurology specialists are distributed unevenly by SMSAs.

Discussion

Our results show that Gini coefficients for neurosurgeon and hospital/clinics able to treat ASI were unequal compared with those of CT and angiography. Japan is known to have the most CT devices per population among other Organisation for Economic Co-operation and Development (OECD) member nations [22]. Therefore, abundant allocation of CT enables easy utilization for residents and is reflected in the low Gini coefficient determined in this study. In contrast, the Gini coefficient of neurosurgeon access was high. Recently, shortage and maldistribution of physicians have been scrutinized in Japan, regardless of specialty [23]. Although the Gini coefficient described a situation of specialist maldistribution yet abundant condition/availability of equipment, it is unclear why hospital/clinics who can handle AIS have been allocated unequally.

The results of population coverage represent the spatial accessibility of each resource for residents. The coverage was calculated based on TT assuming transportation by ambulance using traffic network analysis. The

CT and angiography coverage in Hokkaido was higher than the number of hospitals/clinics, suggesting that accessibility to CT and angiography is not a factor restraining patients to AIS therapy facilities. Conversely, the number of neurosurgeons was lower than the number of AIS therapy facilities. This suggests the possibility that accessibility to AIS therapy facilities is actually determined by the accessibility to neurosurgeons. When considering the coverage by SMSAs (Table 1), there were 17 SMSAs that indicated that neurosurgeon coverage was the lowest aspect of subject resources in 21 total SMSAs, indicating that the allocation of specialists is the primary issue in the provision of AIS treatment in all SMSAs. However, there was an area showing a different finding: Kitasorachi-SMSA (No. 8) has a good ability to treat patients with AIS although the number of angiography equipment was 0 (Table 1). In general, AIS treatment is conducted with a combination of rt-PA and mechanical thrombectomy as recommended by the Japan Stroke Society [http://www.jsts.gr.jp/img/rt-PA02.pdf]. Since mechanical thrombectomy is operated under angiography equipment, the Kitasorachi area is regarded as an area working intensively on rt-PA treatment. This finding suggests that despite the incomplete coverage of resources, promotion of clinical specialization and collaboration enables medical facilities to provide effective AIS treatment. However, as in any case, the existence of a specialist is the most essential aspect to treat AIS (Table 1).

This study reported accessibility by region regarding AIS treatment. We were able to identify resources that determined the accessibility to treatment by any particular region. Government officials could guide policy from this report of resource allocation based on the calculated inequalities. We propose this analysis method to support political decision-making regarding medical resource management.

This study has some limitations. First, The Japanese healthcare system guarantees “free access” to all people for medical care. In this study, we performed accessibility analysis by area, assuming emergency operation of transportation and treatment is completed in a single SMSA. This assumption does not consider medical treatment over multiple areas. Second, we evaluated accessibility by calculating TT based on SMSA, so we could not consider arrival time and stay time in this study. Evaluating accessibility based only on TT mainly reflects relation distribution of population and healthcare resource, and there is a possibility of underestimating the variation of ambulance allocation by a region. When evaluating based on TT for emergency patients, a simulation that comprehensively considers these times is required in the next study.

To expand this study, we must analyze accessibility, reflecting the realities of patient behavior, with this issue. The second shortcoming lies in determining the proper criteria of TT. In general, rt-PA is effective if it is operated within 4.5 hours of the initial AIS [24]. Our setting criterion was 10 minutes, which might be too stringent and may underestimate the actual coverage treatment calculation. Although there is no established standard for the evaluation of RT, transfers must be done quickly as soon as possible in accordance with the Japan Stroke Society [24]. We proposed a new methodology of using Gini coefficient and GIS network analysis of traffic flow to observe relationship between accessibility and healthcare resources. Calculation of Gini coefficient enables policy decision maker to understand the relationship from the view of equal distribution. In addition, using GIS network analysis allow us to grasp more accurate TT with real traffic situation.

In this study, we used 10 minutes as the calculation criterion according to the average time for patient transfer. In general, when an AIS symptom appears, many people cannot correctly diagnose an AIS. Thus, we must consider that our evaluation was conducted based on recommendations and real emergency operational situations and not necessarily guided by optimal treatment outcomes. Finally, as most of this analysis was performed in Hokkaido, these results may not be generalizable to other areas. We would be glad to analyze other areas to determine other factors affecting resource accessibility in future studies.

Conclusions

The data suggests that securing neurology specialists may develop accessibility to AIS treatment and promote early transfer to hospital. Also, specialized angiography equipment necessary for mechanical thrombectomy is not necessarily needed in every SMSA in the Kitasorachi area. These data indicate that clinical specialization and collaboration evolves effective resources allocation of medical equipment. Combining Gini coefficient and GIS network analysis in accessibility can be useful in quantifying and monitoring variation by region. We propose this combination as a new method for helping the government to make evidence-based healthcare planning.

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Figure and Table, formula

Figure1. 21 secondary medical services areas in Hokkaido and demographic information

Figure 2: Mapping of the rate of population coverage by SMSA

Figure 3. Lorentz curve of neurosurgeons, hospitals/clinics, CT, and angiography

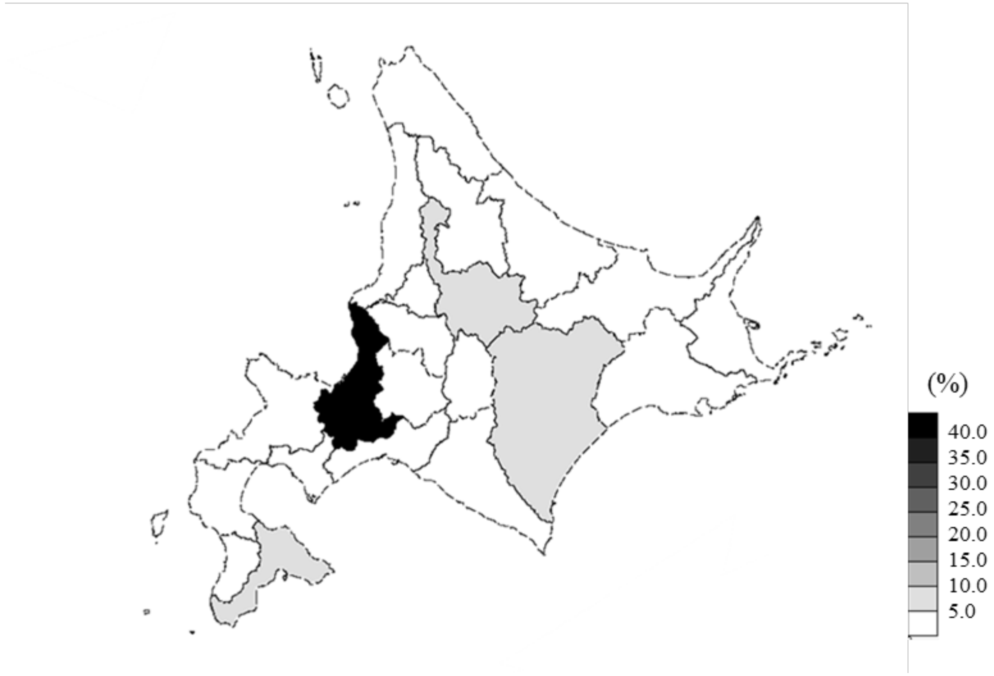
Table 1: Populations residing inside 10-minute Transport time (TT) areas in Hokkaido

Formula (1)

Formula (2)

(A) Each SMSA name and place

(B)The percentage of population by SMSA to Hokkaido overall



(C)Population density by SMSA

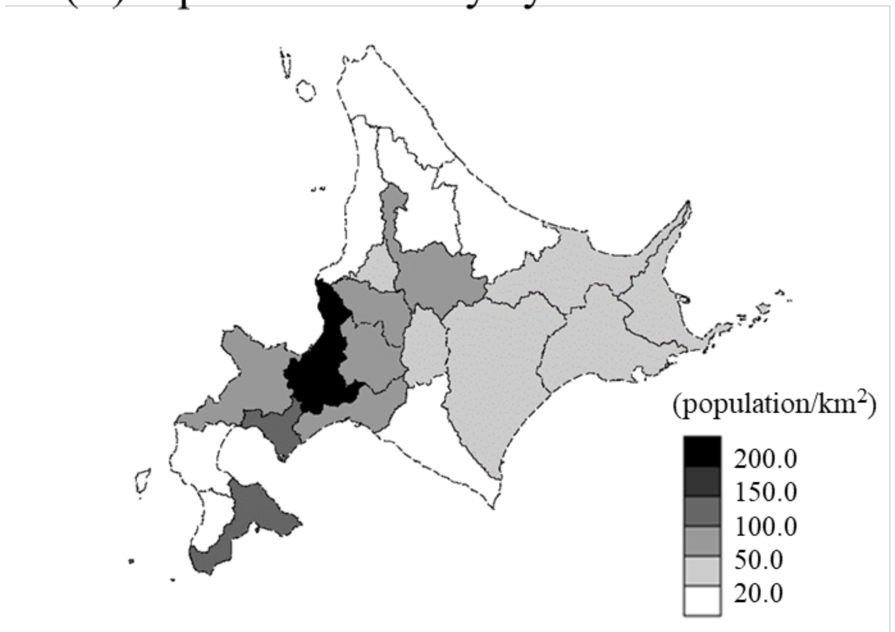


Figure1. 21 secondary medical services areas in Hokkaido and demographic information

Formula (1)

$$\text{The rate of population coverage} = \frac{\text{Size of population within TT in each SMSA}}{\text{Total population size in each SMSA}}$$

Formula (2)

$$G = \left(\sum_{i=1}^{n-1} x_i \cdot y_{i+1} \right) - \left(\sum_{i=1}^{n-1} x_{i+1} \cdot y_i \right)$$

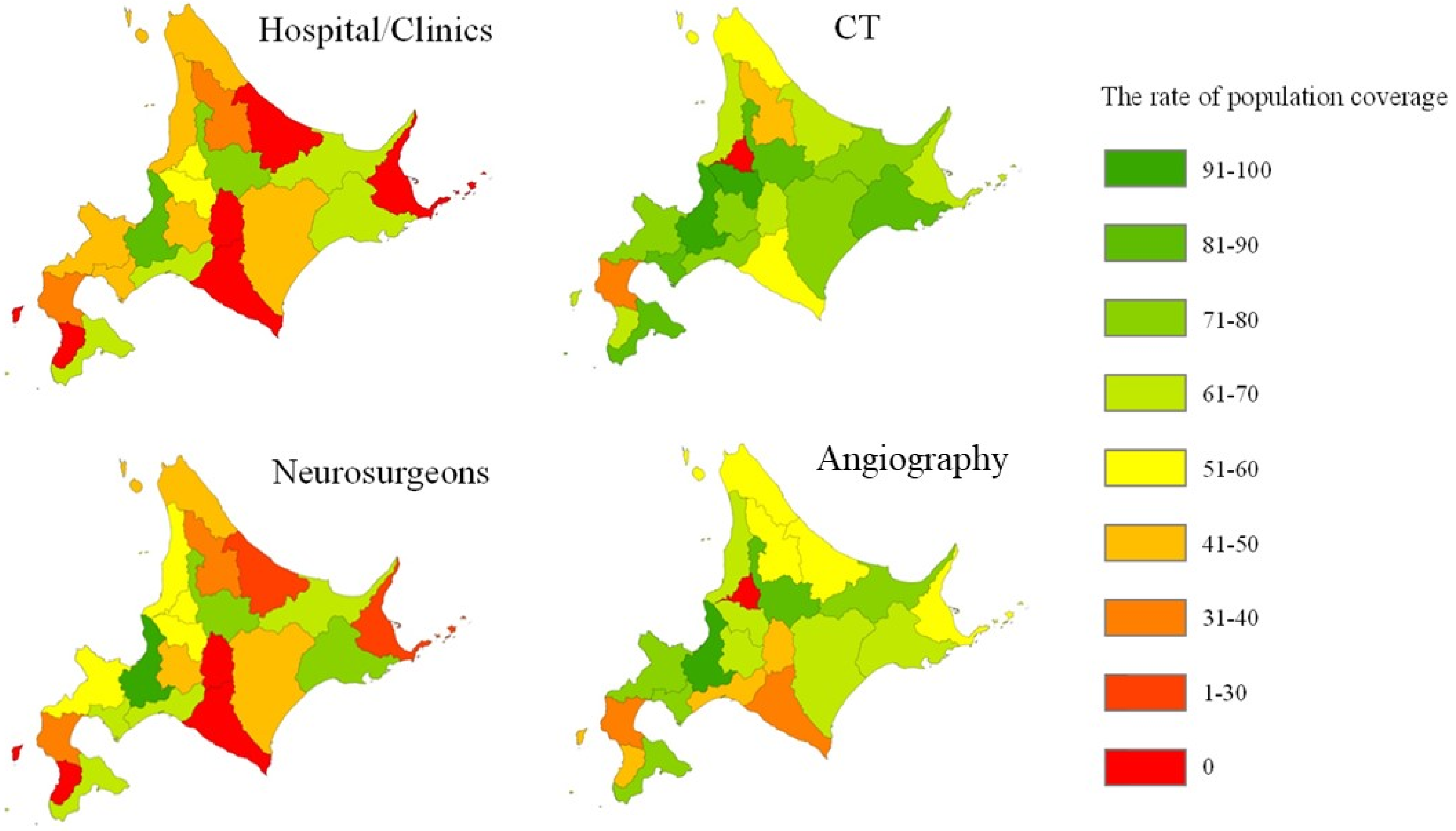


Figure 2: Mapping of the rate of population coverage by SMSA

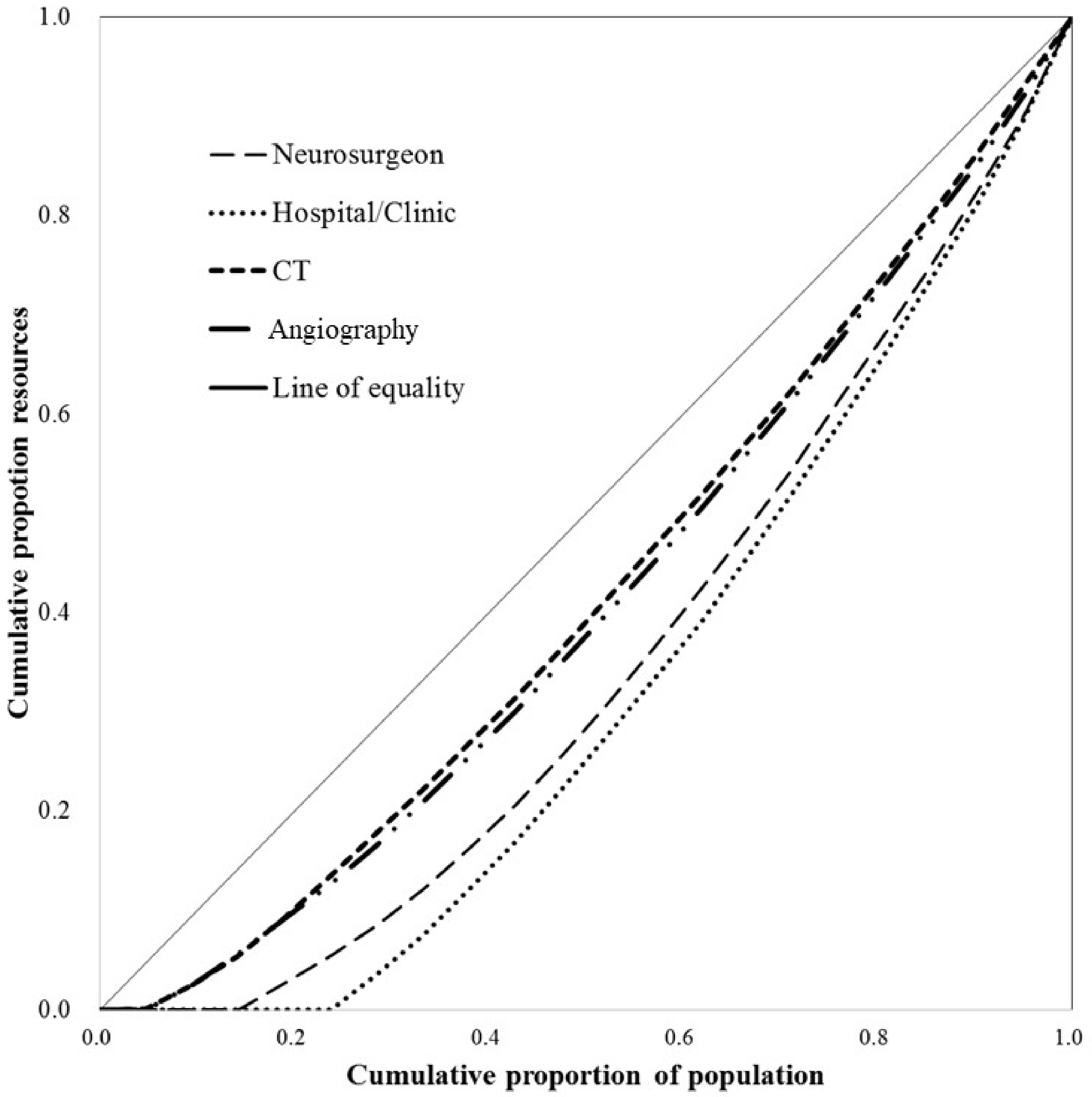


Figure 3. Lorentz curve of neurosurgeons, hospitals/clinics, CT, and angiography

Table1: Populations residing inside 10-minute TT areas in Hokkaido

	SMSA	Population	Inside TT=10minutes, n [%]							
			Hospital/clinic, n	[%]	CT, n	[%]	AG, n	[%]	Neurosurgeon, n	[%]
1	Minamioshima	381,758	244,659	[64.1%]	320,439	[83.9%]	270,621	[70.9%]	257,141	[67.4%]
2	Minamihiyama	23,818	0	[0.0%]	14,776	[62.0%]	10,262	[43.1%]	0	[0.0%]
3	Kitaoshimahiyama	37,363	11,491	[30.8%]	12,775	[34.2%]	11,490	[30.8%]	11,490	[30.8%]
4	Sapporo	2,379,186	2,093,870	[88.0%]	2,281,968	[95.9%]	2,223,006	[93.4%]	2,261,303	[95.0%]
5	Shiribeshi	226,205	110,823	[49.0%]	169,896	[75.1%]	168,867	[74.7%]	125,817	[55.6%]
6	Minamisorachi	167,669	67,468	[40.2%]	122,791	[73.2%]	108,839	[64.9%]	67,656	[40.4%]
7	Nakasorachi	109,469	62,315	[56.9%]	104,443	[95.4%]	76,108	[69.5%]	62,869	[57.4%]
8	Kitasorachi	33,148	19,562	[59.0%]	337	[1.0%]	0	[0.0%]	19,611	[59.2%]
9	Nishiiburi	189,881	94,268	[49.6%]	168,344	[88.7%]	134,168	[70.7%]	127,670	[67.2%]
10	Higashiiburi	214,741	144,184	[67.1%]	158,627	[73.9%]	101,219	[47.1%]	142,958	[66.6%]
11	Hidaka	69,039	0	[0.0%]	41,201	[59.7%]	26,414	[38.3%]	0	[0.0%]
12	Kamikawachuubu	394,482	294,721	[74.7%]	330,451	[83.8%]	327,226	[83.0%]	295,888	[75.0%]
13	Kamikawahokubu	66,593	23,675	[35.6%]	27,835	[41.8%]	39,910	[59.9%]	23,857	[35.8%]
14	Furano	42,970	0	[0.0%]	26,197	[61.0%]	18,340	[42.7%]	0	[0.0%]
15	Rumoi	48,097	22,342	[46.5%]	32,158	[66.9%]	29,064	[60.4%]	24,962	[51.9%]
16	Souya	69,582	29,601	[42.5%]	38,443	[55.2%]	38,322	[55.1%]	30,315	[43.6%]
17	Hokumou	222,745	133,811	[60.1%]	173,397	[77.8%]	163,249	[73.3%]	138,993	[62.4%]
18	Enmon	70,912	0	[0.0%]	46,445	[65.5%]	38,176	[53.8%]	18,543	[26.1%]
19	Tokachi	343,462	167,597	[48.8%]	252,076	[73.4%]	213,031	[62.0%]	168,681	[49.1%]
20	Kushiro	236,869	155,047	[65.5%]	193,883	[81.9%]	160,234	[67.6%]	176,538	[74.5%]
21	Nemuro	76,733	0	[0.0%]	52,788	[68.8%]	43,370	[56.5%]	20,600	[26.8%]
	Total	5,400,990	3,932,648	[73.3%]	4,556,350	[84.4%]	4,190,133	[77.6%]	3,961,071	[67.8%]