Original article

Before-after (1998 and 2008) trend analyses on regional clustering of clinical dentist-to-population ratio in all 1,976 municipalities of Japan

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Abstract

Purpose: The main purpose of this study was to obtain geographic clustering information in order to identify shortages ("cold spots") and surpluses ("hot spots") of dentists in all municipalities of Japan. Methods: Pretreatment steps were conducted to recover the lost comparability between pre-1998 and post-2008 data due to the large-scale merging of municipalities (42.1% reduction) in the Heisei era. Moran's I, LISA and spatial multiple regression analyses with AIC were performed to verify regional clustering. Dependent variables of the regression analyses were the clinical dentist-to-population ratio in 2008 (Model 1) and the difference between 1998 and 2008 (Model 2). Results: The R^2 was 0.8379 ($p<0.0001$) for Model 1 and 0.5832 ($p<0.0001$) for Model 2. The initial dentist-to-population ratio in 1998 showed the highest significance in both models. However, the coefficient of Model 2 was negative, which was exactly the opposite of that of Model 1. Furthermore, indices relating to urbanization and hospital dentist-to-population ratio in 1998 were also highly significant ($p<0.01$) after adjustment for confounding factors. High-High clustered municipalities are located in most urbanized areas, whereas Low-Low clustered municipalities are located in remote areas far from urbanized areas. This study revealed that factors which attract dental clinics are urbanization and hospitals with dental care capabilities. Conclusion: Clinical dentist-to-population ratios have improved only in municipalities in urbanized areas in the past ten years. On the contrary, accessibility of dental treatment has not improved in remote/isolated areas.

Introduction

This study was conducted as part of a series of studies on the supply and demand of dentists in Japan funded by the Health Labour Sciences Research Grant [1] by the Ministry of Health, Labour and Welfare (MHLW) in fiscal 2009 and 2010. Both the shortage of dentists in rural, isolated areas and the excessive concentration of

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dentists in urban areas are problems of fundamental inequity. Dental health policy should be changed in order to rectify this imbalance in the number of dentists operating in dental clinics per 100,000 people (clinical dentist-to-population ratio).

The first purpose of the study was to compare regional clustering of the dentist-to-population ratio by facility type and indices relating to population dynamics.

The second purpose of the study was to evaluate the magnitude of the affect of each index mentioned above on the clinical dentist-to-population ratio in 2008 and the difference between 1998 and 2008, with adjustment for confounding factors.

The third purpose of the study was to obtain geographic clustering information on shortages and surpluses of dentists in all municipalities of Japan, and to identify regional clustering [2,3] areas as so-called "hot spots" (High-High neighboring relationship) [2,3] or "cold spots" (Low-Low neighboring relationship) [2,3].

Finally, based on this analysis we offer our proposals for improving these inequitable conditions of supply and demand of clinical dentists in terms of dental health policy.

Methods

The large-scale merging of cities, towns and villages in the Heisei era (1999-2010) has a great and fatal affect on the comparability [4] of time-series data and before-after data from this period. Therefore, the following pretreatment steps (i and ii) were essential in order to recover the comparability between the two years (1998 and 2008) before conducting the analyses (iii-viii) of regional clustering of clinical dentist-to-population ratio in all municipalities of Japan.

Pretreatment steps

(i) Table of mergers: A table, sorted by year, of municipal merger information from December 31, 1998 to December 31, 2008 was prepared based on data from the Geospatial Information Authority of Japan (GSI) [5], the Japan Geographic Data Center (JDC) [6], and a study on other relevant sites by a geographer [7].

(ii) Shapefile: The table of mergers described in (i) was used to integrate the data on dentists and population described in (a) and (b) below into a shapefile composed of 1,976 municipalities obtained from ESRI Japan [8] on December 31, 2006.

(a) Number of dentists: The number of the dentists practicing in 1998 and 2008 in each municipality by type of institution or facility was obtained from the Survey of Physicians, Dentists and Pharmacists which is conducted every two years by the Ministry of Health, Labour and Welfare (MHLW), Japan [9].

(b) Population: The population of each municipality in 2000 and 2005 was obtained from the National Population Census Survey which is conducted every five years by the Ministry of Internal Affairs and Communications (MIAC), Japan [10].

Analyses

(iii) Basic statistics: Basic statistics were generated for variables related to the data from the national surveys of dentists and population. Coefficient of variation (CV) was calculated as relative standard deviation (RSD) in order to measure disparities among the indices relating to dentist-to-population ratio.

(iv) Moran's I: Univariate and bivariate Moran's I [11] tests were conducted on the relevant variables under second-order "Queen" contiguity weight [12,13]. The statistical significance of Moran's I was determined by a permutation test [11] with 10,000 trials.

(v) SMRM 1: A spatial multiple regression model (SMRM) [13] with ordinary least squares (OLS) estimation and maximum likelihood estimation (MLE) was generated under second-order Queen contiguity weight. The dependent variable for this model was the ratio of dentists per 100,000 population engaged in dental clinics on 31 December in 2008 (CLINIC08R), and the independent variables consisted of six population dynamics indices and two indices : the ratio of dentists per 100,000 population engaged in dental clinics on 31 December in 1998(CLINIC98R), the ratio of dentists per 100,000 population engaged in hospitals on 31 December in 1998 (HOSPITAL98R) relating to dentist-to-population ratio in 1998. A comparison of the two models-OLS and MLE-was performed using Akaike information criterion (AIC) [14] in order to obtain the model with the better "goodness of fit".

(vi) SMRM 2: A second SMRM with OLS and MLE was generated, this time with the difference between CLINIC08R and CLINIC98R (CLINICDIF) as the dependent variable and keeping the same eight independent variables as in analysis (v), again using second-order Queen contiguity weight. Comparison of the two models (OLS and MLE) was again performed using AIC.

(vii) Univariate LISA: A univariate LISA map of CLINIC08R was generated.

(viii) Bivariate LISA: A bivariate LISA cluster map of HOSPITAL98R versus CLINIC08R was generated.

Results

The large-scale merger of cities, towns and villages during the Heisei era resulted in a 42.1% reduction in the number of municipalities, from 3,371 to 1,951 during the ten-year period covered by this study. As shown in Figure 1, data from the surveys of dentists in 1998 and 2008 and census population data from 2000 and 2005 were integrated into the latest shapefile [8] (from December 31, 2006 and consisting of 1,976 municipalities) in order to recover the

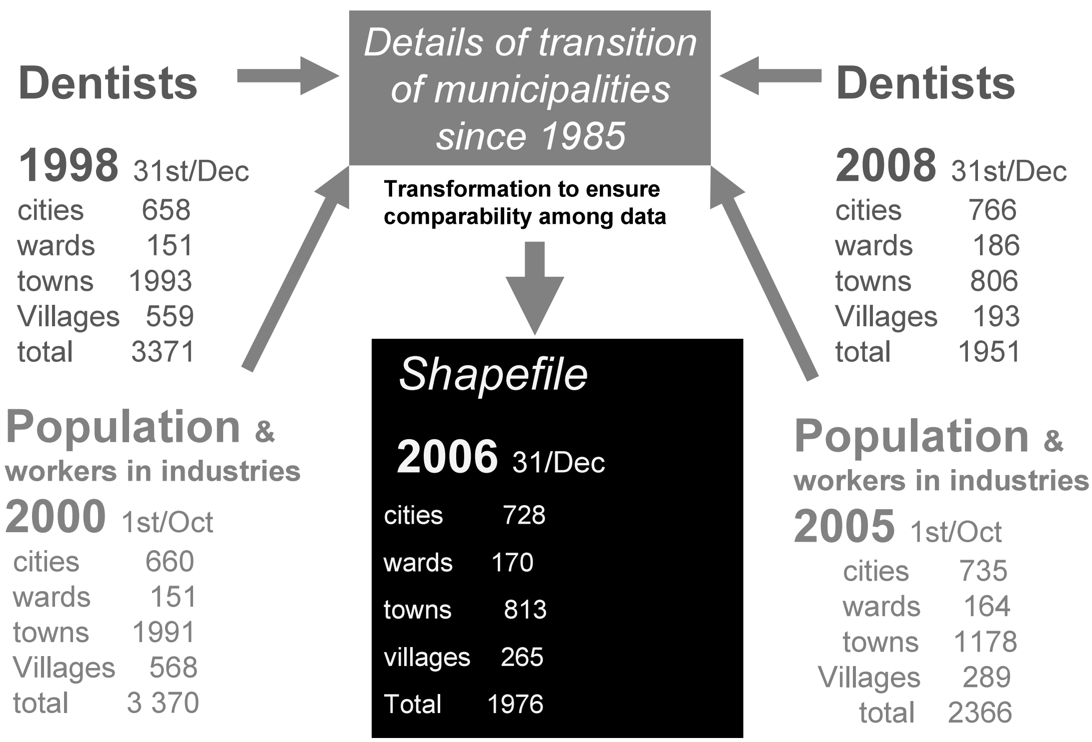

Figure 1. Integration of data from national surveys of dentists and population into shapefile.

comparability of before-after (1998 and 2008) data. For example, 15 municipalities were merged into Niigata City, which was designated as a special city by national government ordinance. Meanwhile, 4 neighboring cities were merged to form Saitama City, which was divided into 10 wards. In Yamanashi Prefecture, Kamiku-ishiki Village was divided into two parts, each of which was merged into a different municipality. The status of both of these municipalities in 1998 and 2008 was verified by the official municipal merger records obtained from GSI [5] and adapted precisely to the December 31, 2006 shapefile provided by ESRI Japan [8] in order to recover the comparability which had been lost due to the large-scale merging of municipalities and which was essential for a before-after study like this one.

Table 1 shows the change in the number of dentists during the 10-year period (1998-2008) by type of institution or facility. The number of dentists practicing at dental clinics changed from 74,126 to 84,613. This is an increase of 14.15%. An increase was observed in all facility types except educational institutions (-1.50%), and the highest increase was seen in hospitals (29.51%) other than educational institutions.

Table 2 provides a detailed description and basic statistics for each of the indices relating to the national surveys of dentists and population. The CV values for the seven variables related to number of dentists range from 0.70 (CLINIC08R) to 14.66 (COLLGE98R). Table 2 also shows that the CV values of CLINIC98R and CLINIC08R are smaller than those of HOSPITAL98R and HOSPITAL08R. The CV values for these indices decreased from 1.08 to 0.70 and from 11.48 to 9.23, respectively. A look at the skewness values of COLLAGE98R, COLLAGE08R, HOSPITAL98R, HOSPITAL08R, CLINIC98R, CLINIC08R, and CLINICDIF reveals that all distributions are skewed to the right side of the mean. Kurtosis shows that all distributions were extremely sharp compared with the normal distribution. However, the reduction of kurtosis (from 617.87 to 393.09) during the ten-year period shows that disparity in the clinical dentist-to-population ratio in Japan has improved

Table 1. Change in the of number of dentists, 1998–2008, by type of institution/facility

	31/12/1998	31/12/2008	Increase %
Total (A+B)	88,061 persons	99,426	12.91
A. Medical facilities	85,669	96,674	12.85
a1 hospitals	11,543	12,061	4.49
a1-1 educational institutions	9,313	9,173	-1.50
a1-2 excluding a1-1	2,230	2,888	29.51
a2 dental clinics	74,126	84,613	14.15
B. other (research institutes, facilities for welfare, administration, etc.)	2,392	2,752	15.05

Source: Survey of Physicians, Dentists and Pharmacists done every two years by MHLW: Ministry of Health, Labour and Welfare, Japan

Table 2. Descriptive information of variables relating to the national surveys of dentists and population

	variable	description	survey[a] dd/mm/yy	n[b]	mean	sd	CV:coefficient of variance	skewness	kurtosis
1	EST1998	Estimated population by census data in 1995 & 2000	1/10/1998	1976	63939.44	94813.94	1.48	3.24	13.87
2	RINCPOP950	Growth rate of population between two years	1/10/1995&2000	1976	-0.75	5.98	-8.01	-0.10	61.81
3	EST2008	Estimated population by census data in 2000 & 2005	1/10/2008	1976	64910.14	98605.10	1.52	3.28	14.39
4	RLT15	The ratio of people 14 years old or under against total population	1/10/2000	1976	14.63	2.13	0.15	-0.17	2.27
5	RBW1564	The ratio of people between 15 - 64 years against total population	1/10/2000	1976	63.70	6.17	0.10	-0.79	5.16
6	RGE65	The ratio of people 65 years old or over against total population	1/10/2000	1976	21.67	6.76	0.31	0.54	0.20
7	RINDUST1	The ratio of employees engaged in primary industry	1/10/2000	1976	2.96	1.18	0.40	0.17	4.42
8	RINDUST2	The ratio of employees engaged in secondary industry	1/10/2000	1976	27.39	8.27	0.30	0.14	-0.34
9	RINDUST3	The ratio of employees engaged in tertiary industry	1/10/2000	1976	59.97	10.82	0.18	0.14	-0.43
10	HOSPITAL98R	The ratio of dentists per 100,000 population engaged in hospitals	31/12/1998	1976	5.56	63.82	11.48	31.34	1150.13
11	COLLAGE98R	The ratio of dentists per 100,000 population engaged in dental or medical collages including affiliated hospotals	31/12/1998	1976	4.20	61.61	14.66	31.11	1134.02
12	CLINIC98R	The ratio of dentists per 100,000 population engaged in dental clinics	31/12/1998	1976	47.68	51.53	1.08	21.38	617.87
13	HOSPITAL08R	The ratio of dentists per 100,000 population engaged in hospitals	31/12/2008	1976	5.36	49.50	9.23	29.49	1047.56
14	COLLAGE08R	The ratio of dentists per 100,000 population engaged in dental or medical collages including affiliated hospotals	31/12/2008	1976	3.68	47.47	12.88	29.17	1022.61
15	CLINIC08R	Ratio of dentists per 100,000 popultion engaged in dental clinics	31/12/2008	1976	53.39	37.56	0.70	14.83	393.09
16	CLINICDIF	Difference between CLINIC08R and CLINIC98R	31/12/2008	1976	5.71	23.84	4.18	-10.64	236.32

Note

a) The national population census is carried out on October 1 every five years by Ministry of Internal Affairs and Communications (MIAC). The Survey of Physicians, Dentists and Pharmacists is conducted on December 31 every two years by Ministry of Health, Labour and Welfare (MHLW), Japan.

b) The number of municipalities in Japan was drastically reduced from 3,371 to 1,951 between December 31, 1998 and December 31, 2008. Therefore, the status of municipalities in both 1998 and 2008 were converted into the status of municipalities on December 31, 2006, when there were 1,976 municipalities. This date corresponds to the latest edition of shapefile. This conversion process ensures the mutual comparability of the before and after data.

considerably.

Table 3 shows the results of the univariate and bivariate Moran's I tests, including significance, for the relevant 16 indices. Univariate Moran's I values of all 9 indices relating to population dynamics range from 0.1871 ($p<0.0001$) to 0.4689 ($p<0.0001$), whereas values for the 7 indices relating to number of dentists range from -0.0184 ($p<0.05$) to 0.2177 ($p<0.0001$). Values for bivariate Moran's I between indices 1-12 and CLINIC08R were all significant ($p<0.0001$). However, values for bivariate Moran's I between indices 1-12 indices and CLINICDIF were significant (almost $p<0.001$) for only 9 indices: EST1998, EST2008, RLT15, RINDUST1, RINDUST2, RINDUST3, HOSPITAL98R, COLLAGE98R, and CLINIC98R.

Table 4 shows the results of the spatial multiple regression analysis (SMRA) with MLE for the factors influencing the clinical dentist-to-

Table 3. Univariate and bivariate Moran's I test of relevant variables

	variable	Moran's I univariate Moran's I a)	p c)	bivariate Moran's I b) with CLINIC08R	p	bivariate Moran's I with CLINICDIF	p
1	EST1998	0.2273	<0.0001	0.1396	<0.0001	-0.0280	<0.0001
2	RINCPOP950	0.2559	<0.0001	0.0715	<0.0001	0.0071	0.4022
3	EST2008	0.2519	<0.0001	0.1481	<0.0001	-0.0320	<0.0001
4	RLT15	0.1871	<0.0001	-0.0397	<0.0001	0.0377	<0.0001
5	RBW1564	0.2306	<0.0001	-0.0010	<0.0001	-0.0010	0.4820
6	RGE65	0.4127	<0.0001	-0.0987	<0.0001	-0.0088	0.1512
7	RINDUST1	0.2159	<0.0001	-0.0349	<0.0001	0.0352	<0.0001
8	RINDUST2	0.4689	<0.0001	-0.0753	<0.0001	0.0173	0.0196
9	RINDUST3	0.3516	<0.0001	0.1699	<0.0001	-0.0171	0.0176
10	HOSPITAL98R	0.0216	0.0118	0.0937	<0.0001	-0.0465	<0.0001
11	COLLGE98R	0.0192	0.0187	0.0920	<0.0001	-0.0456	<0.0001
12	CLINIC98R	0.1866	<0.0001	0.1976	<0.0001	-0.0861	<0.0001
13	HOSPITAL08R	-0.0202	0.0129				
14	COLLGE08R	-0.0184	0.0163				
15	CLINIC08R	0.2177	<0.0001				
16	CLINICDIF	0.0560	0.0006				

Note

a) & b) Univariate and bivariate Moran's I tests were performed under second order Queen contiguity weight.
b) Permutation test for Moran's I: Under the randomization assumption, the observed value of Moran's I is assessed relative to the set of all possible values that could be obtained by randomly permuting the observations over locations in the data set.

population ratio in 2008. The parameters of goodness of fit of the OLS model were R^2 = 0.8367 and AIC = 16688.0, whereas those of the MLE model were R^2 = 0.8379 and AIC = 16676.5. The AIC of the MLE model is smaller than that of the OLS model, and the difference between the AIC values of the two models was 11.5. This shows that the MLE model has superiority over the OLS model in goodness of fit because the difference (11.5) is far greater than 10, which is the rough standard proposed by Burnham and Anderson [14]. Five variables out of 8 were significant, as shown in Table 4. The absolute z-value of the coefficient of CLINIC98R is by far the largest (56.33), and it is highly significant ($p<0.0001$). The second largest absolute z-value, that of RINDUST3, is also highly significant (9.56, $p<0.0001$). Three other variables also have significant absolute z-values: EST1998 (2.82, $p<0.01$), HOSPITAL98R (2.81, $p<0.01$), and RINCPOP950 ($p<0.05$). These results strongly indicate that CLINIC08R is influenced mainly by CLINIC98R, and that after adjustment for confounding factors related to population dynamics, it is influenced secondarily by HOSPITAL98R.

Table 5 shows how SMRA with MLE was used to show the influence of population dynamics factors as well as two indices related to dentist-to-population ratio in 1998 (CLINIC98R and HOSPITAL98R) on CLINICDIF, the change in clinical dentist-to-population ratio from 1998 to 2008. A comparison between the two models, OLS and MLE, was performed to ascertain which model had a better "goodness of fit". The parameters of goodness of fit of the OLS model were R^2 = 0.5813 and AIC = 16688.1, whereas the parameters for the MLE model were R^2 =

Table 4. Spatial multiple regression analysis with MLE for the factors influencing the clinical dentist-to-population ratio in 2008

dependent /independent	variable	Coefficient by MLE[b)]	sd	z-value	p
dependent	W[a)]-CLINIC08R	0.0792	0.0217	3.6532	0.0003
independent	CONSTANT	-1.2871	2.6588	-0.4841	0.6283
	EST1998	1.20E-05	4.27E-06	2.8199	0.0048
	RINCPOP950	-0.1835	0.0775	-2.3680	0.0179
	RLT15	0.2948	0.1552	1.8995	0.0575
	RGE65	-0.1126	0.0607	-1.8538	0.0638
	RINDUST1	-0.2253	0.3165	-0.7119	0.4765
	RINDUST3	0.3348	0.0350	9.5606	0.0000
	HOSPITAL98R	0.0224	0.0080	2.8139	0.0049
	CLINIC98R	0.6057	0.0108	56.3303	0.0000

Note

a) Dependent value was weighted with 2nd-order Queen contiguity criterion. This means that the contiguity matrix is composed of an average of 8 neighbors, with the definition of neighbor including both immediate neighbors which directly share a border or a vertex and secondary neighbors which share a border/vertex with an immediate neighbor.

b) Comparison of spatial model's goodness of fit:

Ordinary least squares (OLS) estimation: $R^2 = 0.8367$; Log likelihood (LL) = -8335.02; Akaike information criterion (AIC) = 16688.0; Schwarz criterion (BIC) = 16738.5; F-value = 1281.86 ($p<0.0001$)

Maximum likelihood estimation (MLE): $R^2 = 0.8379$; LL = -8328.24; AIC = 16676.5; BIC = 16732.5; Likelihood Ratio Test = 13.5478 ($p<0.001$)

0.5832 and AIC = 16682.9. The AIC of the MLE model was smaller than that of OLS, and difference between the two AIC values is 5.2. This indicates that the MLE model has considerable superiority over OLS in terms of goodness of fit because the difference is in the range of 4-7, based on the standard [14] mentioned above. Six of the 8 variables were significant, as shown in Table 5. The absolute z-value of the coefficient of CLINIC98R is by far the largest and highly significant (-36.54, $p<0.0001$). The second highest absolute z-value, that of RINDUST3, is also highly significant (10.64, $p<0.0001$). Three other variables also have significant absolute z-values: EST1998 (3.06, $p<0.01$), HOSPITAL98R (2.58, $p<0.01$), and RGE65 (-2.55, $p<0.05$). After adjustment for confounding factors related to population dynamics, these results reveal that as CLINIC98R increased, CLINICDIF decreased. It is clear at a glance that the influence of CLINIC98R is precisely the opposite in Table 4 and Table 5.

Figure 2 shows the univariate LISA map of CLINIC08R. The six categories in the legend were consolidated into four categories (High-High, Low-Low, High-Low or Low-High, and Neighborless) in order to make the High-High and Low-Low areas clearly visible. The High-High clustered municipalities are located primarily in urbanized areas such as Tokyo, Osaka, and Fukuoka, whereas the Low-Low clustered municipalities are located in remote

Table 5. Spatial multiple regression analysis with MLE for the factors influencing the change in clinical dentist-to-population ratio from 1998 to 2008

dependent /independent	variable	coefficient	sd	z-value	p
dependent	W_CLINICDIF	-0.1229	0.0439	-2.8004	0.0051
independent	CONSTANT	3.3350	2.4219	1.3771	0.1685
	EST1998	1.30E-05	4.26E-06	3.0588	0.0022
	RINCPOP950	-0.1585	0.0770	-2.0588	0.0395
	RLT15	0.1926	0.1516	1.2709	0.2037
	RGE65	-0.1552	0.0608	-2.5528	0.0107
	RINDUST1	-0.0304	0.3195	-0.0953	0.9241
	RINDUST3	0.3625	0.0341	10.6405	0.0000
	HOSPITAL98R	0.0205	0.0080	2.5818	0.0098
	CLINIC98R	-0.3879	0.0106	-36.5394	0.0000

Note

a) Comparison of spatial model's goodness of fit:

Ordinary least squares (OLS) estimation: $R^2 = 0.5813$; LL = -8335.03; AIC = 16688.1; BIC = 16738.5; F-value = 347.32 ($p<0.0001$)
Maximum likelihood estimation (MLE): $R^2 = 0.5832$; LL = -8331.46; AIC = 16682.9; BIC = 16739; Likelihood Ratio Test = 7.1489 ($p<0.001$)

areas far from the urban areas of the four main islands.

The following can be ascertained from Figure 3 and Figure 4:

(i) The bivariate LISA cluster maps of CLINIC98R vs. CLINICDIF in southern Kanto, Tokai, northern Kinki, and Kyushu areas have been extracted from the full map because these areas clearly show characteristic distributions such as High-High areas, areas with a high clinical dentist-to-population ratio in 1998 and a high increase in the clinical dentist-to-population ratio over the 10-year period, and areas where people moved to surrounding areas from the center of each urbanized area.

(ii) On the other hand, Low-Low areas, as well as areas with a low clinical dentist-to-population ratio in 1998 and a low increase in the clinical dentist-to-population ratio during the 10-year period, are located far from urbanized areas, particularly in the border areas of Shizuoka, Nagano, Gifu, and Aichi prefectures as seen in Figure 3.

(iii) High-High areas are located in the areas surrounding the urbanized area of Kyushu Island. This phenomenon visually illustrates the strong relationship between CLINIC98R and CLINICDIF shown in Table 5.

Discussion

Comparability in time-series studies

In before-after and other time-series studies are performed, comparability must be confirmed or recovered as a precondition of analysis. The large-scale merging of cities, towns and villages during the Heisei (1999-2010) era has great influence on the comparability of studies that make use of data collected by these municipalities. For example, Tsutsumi et al. [15] proposed estimation using a SLM (spatial lag

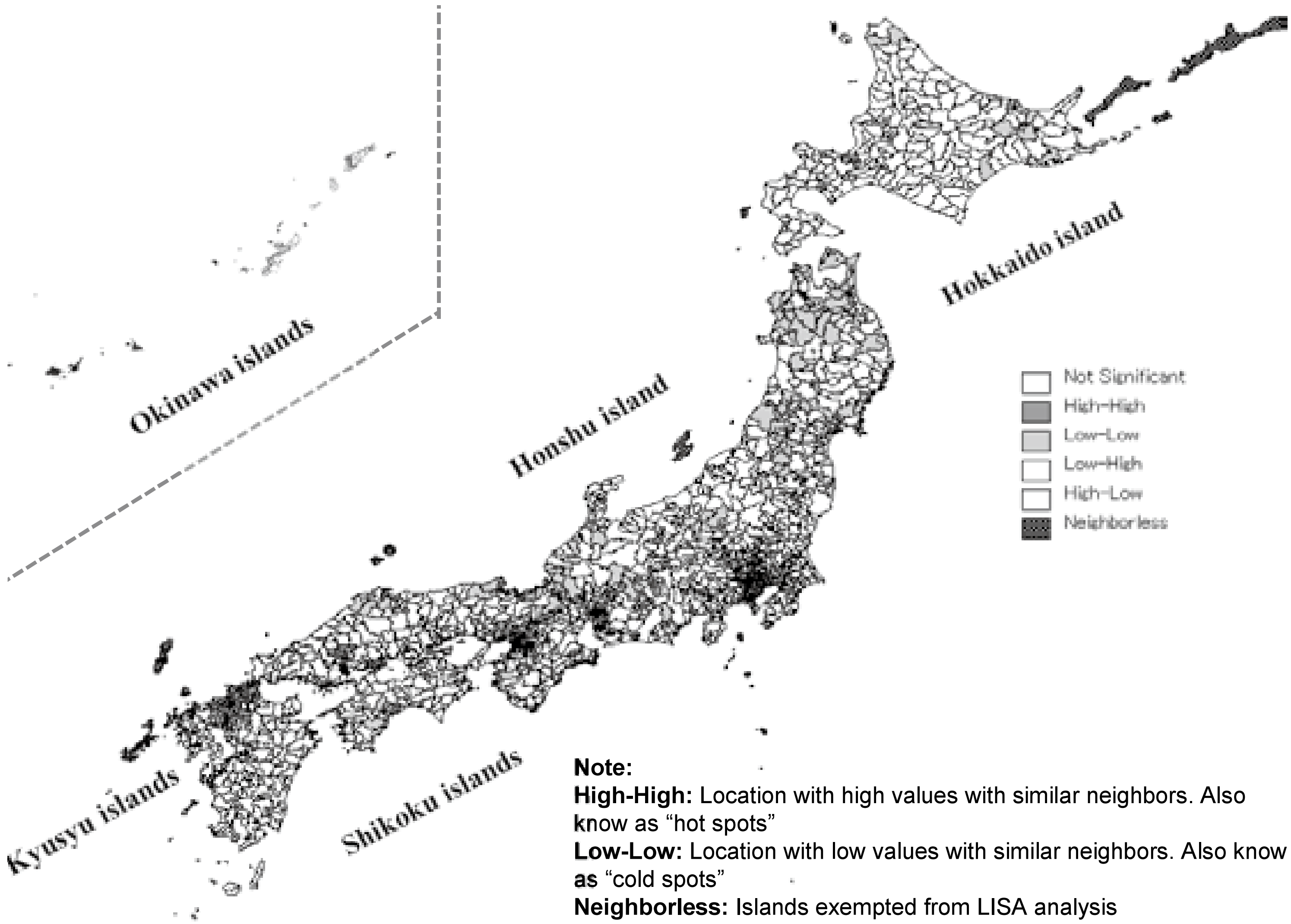

Figure 2. Univariate LISA map of number of dentists engaged at dental clinics per 100,000 population in 2008.

CLINIC98R: number of dentists engaged at dental clinics per 100,000 population in 1998

CLINICDIF: difference between number of dentists engaged at dental clinics per 100,000 population in 1998 and 2008

Figure 3. Bivariate (CLINIC98R vs. CLINICDIF) cluster map of Kanto-Tokai-Kinki areas

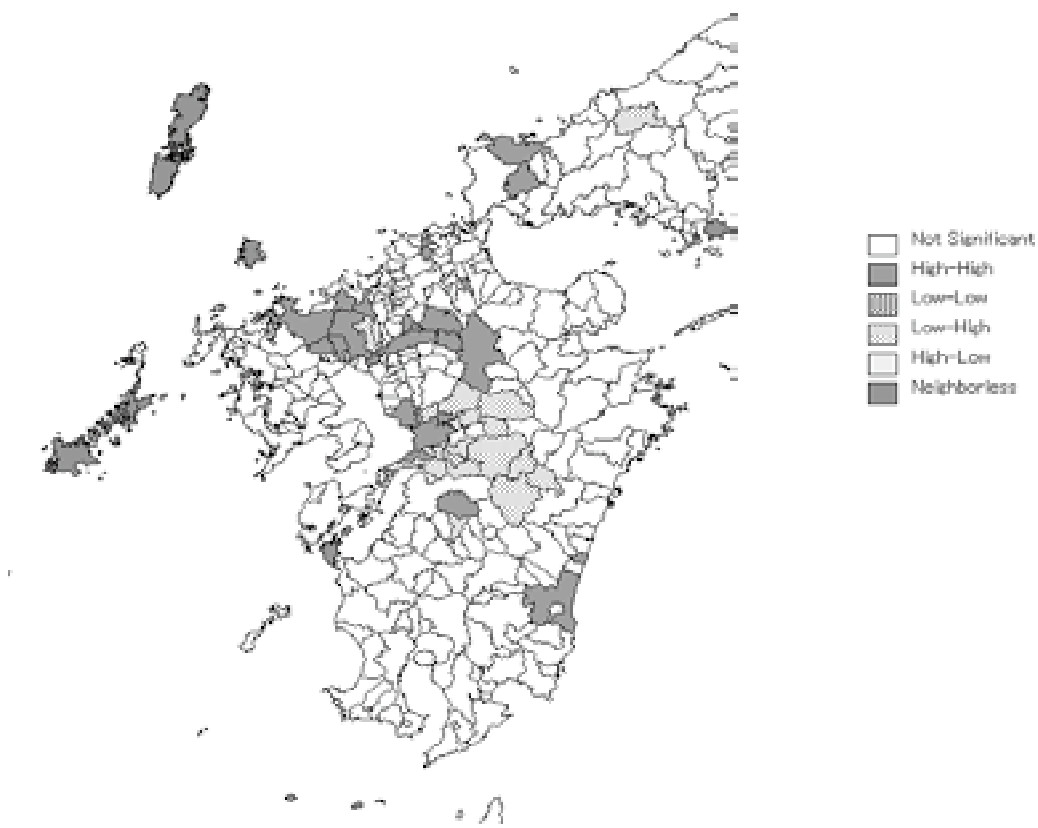

Figure 4. Bivariate (CLINIC98R vs. CLINICDIF) cluster map of Kyushu area

model) in order to adjust for the Great Merger problem. In the present study, in most cases the procedures for ensuring comparability were not so problematic because information on the exact changes in the status of municipalities during the 10-year period could be obtained using GSI and other sources. However, more complicated calculations were required in a few cases, such as Saitama City, where both merging and re-division into wards occurred.

The significance of regional clustering and disparity studies

Studies on regional differences and income disparity or poverty have been conducted since the 1930s using the Gini coefficient (or Lorenz curve) [16] or coefficient of variation (CV) [17]. However, Moran [11] proposed a new method for the quantification and analysis of regional differences and disparity in the 1950s, and Luc Anselin [12] improved the usability of Moran's I (global Moran) test drastically when he developed LISA (local Moran) [13] in the 1990s. Existing methodologies such as the Gini coefficient or CV could not deal with geographical contiguities (similarity among neighborhoods). In other words, the value of each index never changes even if data records are shuffled randomly and the location record numbers are changed. In order to evaluate and quantify contiguity by spatial analyses such as Moran's I test and LISA, the results of spatial analyses must be changed by shuffling the data records. Ayadi, et al. [18] analyzed geographic determinants of welfare and poverty in Tunisia using Moran's I statistics. Strauss, et al. [19] investigated the geographical distribution of the standardized morbidity rates (SMR) of heart disease by spatial analysis at the district level using Moran's I statistic. Horner, et al. and Cheng, et al. [20] demonstrated the heterogeneity of the prescribing pattern of a cardiovascular drug in Taiwan using Moran's I statistics and LISA. Wang [21] showed China's regional (provincial) income disparities and many indices by using spatial analysis methods.

However, epidemiological studies combining time-series data and spatial analysis methods, such as in the present study, are still very rare [22,23].

Generally, humans have an excellent visual ability to identify hidden shapes or recognize specific patterns within a very complex pattern composed of a huge number and various types of units (dots, lines, shapes, colors, etc.) in natural scenery or optical illusions by painters. At the same time, however, it cannot be denied that humans are likely to confuse random patterns with non-random patterns. Humans' recognition of random patterns is thought to be connected to spatial association values [24] of shapes. Namely, humans are likely to misrecognize meaningless shapes (random shapes) as meaningful when the shapes have a high spatial association value. It is very hard to identify random patterns on a choropleth map consisting of several different colors or cross-hatched patterns. Furthermore, it is almost impossible to identify regional clustering (such as hot spots or cold spots) with the naked eye unless regional clustering is automatically categorized by the LISA method.

The significance of spatial analysis methods is that it provides an objective qualification of regional clustering and thereby eliminates subjective misrecognition of patterns.

In this study, we employed a Queen's second-order contiguity matrix, which considers two geographic units to be neighbors if they directly share a border or a vertex or if they have a common neighbor with which they share a border or a vertex. Contiguity is verified in 4 directions from an arbitrary area in the Rook method, but 8 directions in the Queen method. Generally, the Queen method is preferable due to its higher power to detect regional clustering compared with Rook method.

Regional clustering of clinical dentist-to-population ratio

According to our previous study [25], Japan has seen a continuous and nearly linear ($r \geqq 0.96$) increase in the dentist-to-population ratio for 20 years (1982-2002), and there was no change in the differences among the prefectures although the slope angle of the regression lines varied widely. Most prefectures with national dental schools had steep slopes. Nine of the 11 prefectures with national dental schools were ranked among the ten prefectures with the steepest increase in clinical dentist-to-population ratio over the 20-year period. This trend remained unchanged after adjusting for many socioeconomic confounding factors related to urbanization and population dynamics. It is clear that the establishment of new national dental schools (or departments of dentistry) between 1965 and 1976 by the Ministry of Education, Culture, Sports, Science and Technology (MECSST) strongly contributed to the increase in clinical dentist-to-population ratio in those prefectures. However, the extension of this effect to neighboring prefectures was not significant [25]. The results of that study required further study in order to verify the spillover effects on the distribution of clinical dentists, because the spatial contiguous relationship of the dentist-to-population ratio among municipalities had not yet been analyzed in Japan.

As shown in Table 4, CLINIC98R is the most powerful indicator to predict CLINIC08R. However, this high significance merely means that most dental clinics located in a given municipality in 1998 remained in the same municipality 10 years later. It seems that as far as dental clinics are concerned, the competitive logic of the market has not been a factor in urban areas for a long time, and this may be due to the fact that dental clinics have strong economic advantages and stability that can be attributed to the national insurance system and the prevalence of dental disease.

On the contrary, the z-value of CLINIC98R in Table 5 is negative and highly significant, precisely the opposite of the result of Table 4, whereas the z-values both of RINDUST3 and EST1998 are almost same as those of Table 4. These results reveal that the competitive logic of the market in urban areas has begun to affect the clinical dentist-to-population ratio in the past 10 years.

The fact that urbanization is a factor that attracts dental clinics is shown in the results of EST1998 or RINDUST3 as shown in Table 4. Furthermore, this study revealed that HOSPITAL98R was also a factor attracting dental clinics. This is consistent with our previous findings [25] that national dental schools are a factor in the establishment of dental clinics at the prefectural level. The main role of hospitals with dental care capabilities[26] is secondary dental care for patients who also have other serious diseases or injuries such as facial bone fracture, diabetes mellitus, or cardiovascular diseases. This seems to be why dentists are likely to establish new dental clinics in neighboring areas.

The behaviors of dentists in establishing dental clinics should be considered from not only a macro perspective but also a micro perspective. According to an interview-based study by Suda and Suetaka [27] in 1988 focusing on the reasons of dentists in deciding where to establish their practices, six independent trend patterns were observed in the location of dental practices in Japan. Of the six trends pointed out in that study, the following three are particularly informative in explaining the results of this present study.

Trend 1: The ratio by the number of practitioners in the prefecture to the number of dentists coming from the same prefecture (the practice ratio) varied from 0.52 (Yamagata) to 1.56(Chiba). This ratio was especially high in large urbanized cities.

Trend 2: The leading reasons dentists gave for selecting the location of their practices were economic context, successor-related issues, management of the practice, and living conditions.

Trend 3: Fewer new practices are being established in large cities, but steep increases are being seen in prefectures surrounding large cities. However, increases are not expected in rural and remote prefectures.

The clinical dentist-to-population ratio in 2008 shown in Table 4 and Figure 2 are consistent with Trend 2. Before-after trends observed in Table 5 and Figures 3 and 4 are consistent with Trend 3. Clinical dentist-to-population ratios have increased in municipalities surrounding urban areas (Figures 3 and 4), but there seems to be an insufficient supply of dentists in remote or isolated municipalities far from urban areas, in the northeastern region of Hokkaido, in the Tohoku area, in several of the prefectures facing the Japan Sea, and in the mountainous areas of Honshu Island.

Al-Jarallah, et al. [28] projected the future demand for dentists in Kuwait for the years 2007 to 2020 based on the period from 1994 to 2006. They considered the supply and demand of dentists in Kuwait in the light of emerging variables such as increasing population, economic growth, changes in dental care, education strategies, and changes in the demographics of dentists. Economic growth in Japan has been stagnant for long time, and this situation seems likely to continue for the foreseeable future. Furthermore, the demographic make-up of dentists in Japan depends on the number of dental schools.

National measures to adjust the supply of dentists in Japan have consisted of two opposite phases[2][29-31], namely the rapid increase measures up to the 1970s and the restraint measures since the 1980s. When the initial rush to establish dental schools began, nineteen dental schools (departments of dentistry) out of the current 29 were established from 1965-1979. Nine of those were national schools, and 10 were private schools. However, MHLW and MECSST reversed the direction of the policy on supplying dentists in the 1980s by enacting comprehensive measures to reduce the number of new dentists, including a reduction in the number of places available at each dental school by MECSST and adjustment of the level of difficulty of national dental examination by MHLW. These policies were based on projections and proposals by the acting investigative commission for supply and demand of dentists in Japan.

Further validation of the influence of the existence of national dental schools on the dentist-to-population ration could not be conducted in this municipality-level study, because only 11 municipalities out of 1,976 have national dental schools. Therefore, the number of dentists practicing in municipalities with dental school-affiliated hospitals was verified instead. The results indicate that the existence of such a hospital consistently contributed to an increase in the clinical dentist-to-population ratio.

Proposal on the supply of dentists

Therefore, we propose additional concrete plans for adjusting the supply and demand of dentists in Japan based on our two studies. The Low-Low areas shown in Figure 2 should be considered as candidates for the establishment of national post-graduate dental training centers including hospitals with dental facilities, because such hospitals are likely to attract dentists to establish practices in neighboring areas. Furthermore, this measure would be effective in providing dentists with an incentive to establish dental clinics in Low-Low areas. It would also be useful to introduce a flexible relative value unit (10-12 yen) instead of the current fixed 10 yen at dental clinics located in the Low-Low areas and

Neighborless areas (isolated islands) shown in Figure 2. This new system would provide an incentive for dentists to open dental clinics in remote and isolated areas because it will ensure a maximum of 20% increase in income. However, the assumption that the competitive logic of the market is effective in rural areas needs to be verified first.

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References

1. Takiguchi T, Aoyama H, Fukai K, Ando Y. Studies on the supply and demand of dentists in Japan funded by the Health Labour Sciences Research Grant by the Ministry of Health, Labour and Welfare (MHLW) in fiscal 2010. 2010 ; 281-207.(in Japanese) Available from: http://www.niph.go.jp/soshiki/koku/oralhealth/juq/jyukyu/docu22/docu22_19.pdf (accessed on 1st November, 2011)
2. Takiguchi T. A review of oral epidemiological statistics-Part VII: The bases of Spatial Geographical Epidemiology 1st follow-up review. Health Science and Health Care. 2009; 9(1):19-32. (in Japanese with an English abstract)
3. Takiguchi T. A review of oral epidemiological statistics-Part VIII: The bases of Spatial (Geographical) Epidemiology 2nd follow-up review. Health Science and Health Care. 2010; 10(1): 4-19. (in Japanese with English abstract)
4. Takiguchi T. A review of oral epidemiological statistic-Part V: The bases of Trend Analysis 2nd follow-up review. Health Science and Health Care. 2008; 8(1): 19-33. (in Japanese with English abstract)
5. The Geospatial Information Authority of Japan (GSI). (in Japanese) Available from: http://www.gsi.go.jp/ENGLISH/index.html (accessed on 1st December, 2010)
6. Japan Geographic Data Center (JDC). (in Japanese) Available from: http://www.kokudo.or.jp/marge/change.html (accessed on 1st December, 2010)
7. Ishida S. Transition (1889-) of municipalities in Japan. (in Japanese) Available from: http://www.tt.rim.or.jp/~ishato/tiri/code/code.htm (accessed on 1st December, 2010)
8. ESRI Japan. Shapefile of all municipalities in Japan as of 31st December, 2006. (in Japanese) Available from: http://www.esrij.com/products/gis_data/japanshp/japanshp.html (accessed on 1st December, 2010)
9. Ministry of Health, Labour and Welfare (MHLW), Japan. Survey of physicians, dentists and pharmacists (conducted every two years). (in Japanese) Available from: http://www.mhlw.go.jp/toukei/list/33-20.html (accessed on 1st September, 2010)
10. Ministry of Internal Affairs and Communications (MIAC), Japan. National population census survey (conducted every five years). (in Japanese) Available from: http://www.e-stat.go.jp/S13/estat/GL02100104.do?tocd=00200521 (accessed on 1st December, 2010)
11. Moran P. The interpretation of statistical maps. Journal of the Royal Statistical Society.1948;10: 243-251.
12. Anselin L, Bera AK, Florax R, Yoon MJ. Simple diagnostic tests for spatial dependence. Regional Science and Urban Economics. 1996; 26: 77-104.

13. Anselin L (GeoDa Center). Exploring Spatial Data with GeoDaTM : A Workbook. 2005; 140-164. Available from: http://geodacenter.asu.edu/system/files/geodaworkbook.pdf (accessed on 1st August, 2010)
14. Burnham KP, Anderson DR. Colorado Cooperative Fish and Wildlife Research Unit (USGS-BRD). Multimodel inference understanding AIC and BIC in model selection. Sociological Methods & Research. 2004; 33(2): 261-304.
15. Tsutsumi M, Murakami D. A countermeasure against a change in the areal unit for statistical data brought about by municipal mergers: An analysis by spatial econometric models. 2010; 1-18. (in Japanese) Available from: http://gis.sk.tsukuba.ac.jp/NewGISpage/20100220/9_tsutsumi.pdf (accessed on 1st December, 2011)
16. WHO Regional Office (PAHO). Gini coefficient and Lorenz curve. 2011. Available from: http://www.paho.org/english/dd/ais/be_v26n2-en-desigualdades_3.htm (accessed on 2nd January, 2010)
17. De P, Ghosh B. Effects of infrastructure on regional income in the era of globalization: New evidence from South Asia. Asia-Pacific Development Journal. 2005; 12(1): 81-107.
18. Ayadi M, Amara M. Spatial patterns and geographic determinants of welfare and poverty in Tunisia. 2008;1-24. Available from: http://www.erf.org.eg/CMS/uploads/pdf/1224079400_15thAC_LBR_Ayadi_Amara.pdf (accessed on 25th November, 2011)
19. Strauss R, Pfeifer C, Ulmer H, Mühlberger V, Pfeiffer KP. Spatial analysis of percutaneous transluminal coronary angioplasty (PTCA) in Austria. Eur J Epidemiol.1999 ;15(5) : 451-459.
20. Cheng LC, Chen YC, Liu TM, Yang YHK. Using spatial analysis to demonstrate the heterogeneity of the cardiovascular drug prescribing pattern in Taiwan. BMC Public Health. 2011; 11: 380-388.
21. Wang J. China's regional disparity in demographic transition: A spatial analysis. The Review of Regional Studies. 2008; 38(3): 289-317.
22. Impoinvil DE, Solomon T, Schluter WW, Rayamajhi A, Bichha RP, et al.The spatial heterogeneity between Japanese encephalitis incidence. Distribution and Environmental Variables in Nepal. PLoS ONE.2011; 6(7): 1-11.
23. Takiguchi T, Fukai K, Ando Y, Aoyama H, Yamamoto T, et al. Spatial analyses of regional clustering of time-series trend of dmft index amon15-year-old Japanese children in all 47 prefectures of Japan over 25-year period, 1981—2006. J Dent Hlth. 2010; 60: 139-151. (in Japanese with an English abstract)
24. Clark HJ, Ronald L, Knoll P. Variables underlying the recognition of random shapes. Perception & Psychophysics. 1969; 5(4) : 221-224.
25. Takiguchi T, Fukai K, Aoyama H, Ando Y, Takaesu Y. The relationship between dental schools and the supply of dentists in the 47 prefectures of Japan for a 20-year period-analyzed with the generalized linear models (GLIM). J Dent Hlth. 2005; 55: 524-536. (in Japanese with an English abstract)
26. Kiriyama K, Nobehara H. The role of the department of oral surgery in hospitals and the future prospects. Hiroshima Kenritsu Byoin Ishi. 1996; 28(1): 7-10. (in Japanese)
27. Suda Y, Suetaka T. A study on the location of dental practices in Japan. J Dent Hlth.1988; 38: 54-69. (in Japanese with an English abstract)
28. Al-Jarallah KF, Moussa MA, Al-Duwairi Y, Zaatar E, Al-Khanfar KF. The dentist workforce in Kuwait to the year 2020.

Community Dent Health. 2010; 27(3): 178-83.
29. Mitufusa. Future perspective of supply and demand of dentist in Japan. THE NIPPON Dental Review. 1984; 495: 58-67. (in Japanese)
30. Ohkawa Y, Okada S, Kamijyo H, Miyatake K. The study on projection of supply and demand in future. J Public Health Dent.1995; 45(4):742-743. (in Japanese)
31. Morimoto M, Shizukuishi S, Kawabuchi K,Ouchi A, Miyatake K. The study on projection of supply and demand of dentists. J Public Health Dent.1998; 8(4):546-547. (in Japanese)