Original Article

An analysis of disparities in the changes of cancer mortality rates among prefectures in Japan using age-period-cohort analysis

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Objectives In this study, we compared the decrease in cancer mortality rates among prefectures in Japan using age-period-cohort (APC) analysis.

Methods We used the cancer mortality data of each prefecture in Japan, as determined by the Vital Statistics, over 5-year periods from 1995 to 2015. Records of the number of mortalities in each 5-year age group from 40–44 to 85–89 years age was collected. We fitted a Bayesian APC model to the data of each prefecture and estimated the birth cohort effect on cancer mortality rates in the prefectures over 5-year periods ranging from 1916–1920 to 1971–1975. In addition, we calculated the ratio of the mortality rate of each prefecture to that of the entire country for each birth cohort.

Results Our APC analysis revealed that the decrease in the age-adjusted cancer mortality rates was mainly attributable to a reduction in the cohort effect on the rates in men and to reduction in the cohort and period effects on the rates in women. The magnitude of reduction in cohort effect varied by prefecture for men and women. Several prefectures having a government ordinance-designated municipality tended to show a higher reduction than those that do not. Spearman's correlation coefficient between the population size of prefectures and the percentage reduction in cohort effect was 0.370 in men. In addition, the relative ranking of the prefectures based on cancer mortality rates greatly varied by birth cohorts, particularly in men.

Conclusion A disparity exists in the percentage reduction in the cohort effect among prefectures. In each prefecture target cohorts with higher than average cancer mortality rates must be identified to implement specific countermeasures for cancer prevention. In addition, for each prefecture, assessment of lifestyle differences that might be related to cancer mortality among birth cohorts is important for reducing cancer mortality in the more recent birth cohorts.

Key words: age-period-cohort analysis, Japan, cancer, mortality rate, prefecture, disparity

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I. INTRODUCTION

Japan is one of the countries that have the highest life expectancies in the world, and life expectancy is continuing to increase[1]. However, it is also known that life expectancy varies among prefectures in this country. According to the life table of prefectures in 2015, the life expectancy of Shiga Prefecture was 81.78 years for men[1], which was the highest among the prefectures. Conversely, that of Aomori Prefecture is 78.67 years, and the disparity of life expectancy among prefectures has increased in recent decades[2]. Cancer is the leading cause of mortality in Japan, and according to the Vital Statistics[3], 373,584 people died of cancer in 2018. Cancer mortality rates also vary among prefectures, and the difference in cancer mortality rates among prefectures is considered a contributing factor to the disparity of life expectancy. It has been revealed that the disparity of age-adjusted cancer mortality rates among prefectures widened from 2001 to 2014[4], and the rates of decreases of age-standardized cancer mortality over time have differed among prefectures. Although the disparities of cancer mortality rates among prefectures are often evaluated using age-standardized mortality rates of certain years, there are also disparities regarding the percentage decreases of age-standardized cancer mortality rates or the magnitude of changes in cohort effects on cancer mortality rates. However, the disparity of changes in cancer mortality rates among prefectures has not been analyzed. In addition, the difference in the percentage decreases of cohort effects among prefectures has not been clarified.

As an analytical method for decomposing statistics

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into age, period, and cohort effects, age-period-cohort (APC) analysis is often used[5]. Although APC analyses have been conducted for several cancer types in Japan[6~8], APC analysis has not been frequently used to assess differences in mortality rates among prefectures. Recently, an APC analysis of disparities among prefectures regarding pneumonia, suicide, and cerebrovascular disease-related mortality was conducted[9], and it was revealed that the cohort effects on mortality rates have changed among birth cohorts for each prefecture. Likewise, by analyzing the cancer mortality rates of each prefecture using APC analysis, we can clarify the differences in the trends of cohort effects among prefectures. Moreover, using an APC model, we can compare mortality rates between each prefecture and the nationwide average for each cohort.

In this study, we analyzed the disparities of the percentage decreases of cancer mortality rates among prefectures with a specific focus on cohort effects and evaluated the difference of the trends of cohort effects among prefectures.

II. MATERIALS AND METHODS

1. Materials

We used cancer mortality data for each prefecture taken from the Vital Statistics in Japan[10] for every 5-year period from 1995 to 2015. The population statistics data that were grouped by sex, age, and prefecture were obtained from the Census[10]. Data regarding mortality and population were obtained from the website of the National Cancer Center[10].

As a statistical analysis, we calculated the age-standardized cancer mortality rate of each prefecture using the population in 1995 as the standard population for men and women. In addition, we calculated the percentage decrease of age-standardized cancer mortality from 1995 to 2015 for each prefecture. Then, we used the Bayesian APC model to extract the cohort effects of the prefectures. We fitted a univariate APC model[5] to the data of each prefecture. For this calculation, y_{ij} was set as the mortality rate for age group i $(1,\cdots,I)$ in year j $(1,\cdots,J)$ of a prefecture. In addition to the data of all 47 prefectures, we modeled the data of the entire country of Japan. Therefore, the total number of fitted models was 48. In the model, y_{ij} was assumed to follow the following Poisson distribution with a mean of λ_{ij}:

$$y_{ij} \sim Poisson(\mu_{ij}),$$
$$\log(\mu_{ij}) = \delta + \alpha_i + \beta_j + \gamma_k + z_{ij} + \log(n_{ij})$$

where δ is the intercept; α_{ij} is the effect of age group; β_j is the period effect; γ_k $(k=1,.., K)$ is the cohort effect; z_{ij} is the random effect defined for each prefecture, year, and age group; and n_{ij} is the corresponding population. For the identifiability of the parameters, the restriction that $\Sigma_{i=1}^{I}\alpha_{ij} = \Sigma_{j=1}^{J}\beta_j = \Sigma_{k=1}^{K}\gamma_k = 0$ was used. z_{ij} was assumed to be generated from a normal distribution with a mean of zero. Concerning the priors of each effect, random walk of the first order was used to identify the parameters.

In addition, we calculated the mortality rate ratio for each prefecture relative to the all of Japan. For example, the mortality rate ratio between a prefecture (g) and all of Japan for a certain cohort k was calculated as follows:

$$\exp(\delta_g + \gamma_{kg}) / \exp(\delta_{all} + \gamma_{k,all})$$

In this formula, δ_g represents the baseline mortality rate of a prefecture (g), and δ_{all} represents that of all of Japan. Also, γ_{kg} represent the cohort effect of cohort k for a prefecture (g), and $\gamma_{k,all}$ represents that for all of Japan.

Age groups were defined in 5-year units from 40–44 to 75–79 years old in the data. Regarding the birth cohort, the cohort of patients born from 1916 to 1920 served as the first cohort in the analysis, and that of patients born from 1971 to 1975 was the last cohort. To estimate the parameters, we used the Hamiltonian Monte Carlo method[11].

In order to ascertain the goodness-of-fit of the APC model, we compared it with Age model, Age-period model, and Age-cohort model based on deviance information criterion. All statistical analyses were conducted using R 3.5.1 software[12].

III. RESULTS

Table 1 depicts the age-standardized cancer mortality rates of each prefecture from 1995 to 2015 for men and women. Although the age-standardized mortality rate of all prefectures decreased from 1995 to 2015, the percentage decrease greatly differed among the prefectures. The highest cancer mortality rate in 1995 was recorded for Osaka, whereas the rate was highest for Aomori in 2015.

Table 1 also depicts the percentage decreases of age-standardized cancer mortality rates between 1995 and 2015 by prefecture. Hyogo Prefecture had the largest percentage decrease in mortality of 38.2%, followed by 37.9% for Hiroshima rates. Conversely, the Aomori Prefecture had the smallest percentage decrease in mortality rates of 21%, followed by 21.9% for Kochi. The percentage decrease of cancer mortality rates was generally smaller for women than for men. The prefecture with the largest percentage decrease in mortality rates over time for women was Shimane (28.1%), followed by Osaka (26.4%). Conversely, the smallest percentage decrease in mortality rates was recorded for Aomori (7.7%), followed by Fukushima (9.3%). Although the percentage decrease in mortality and the age-standardized mortality rate were not necessarily correlated, the rates in Aomori were worst among the prefectures.

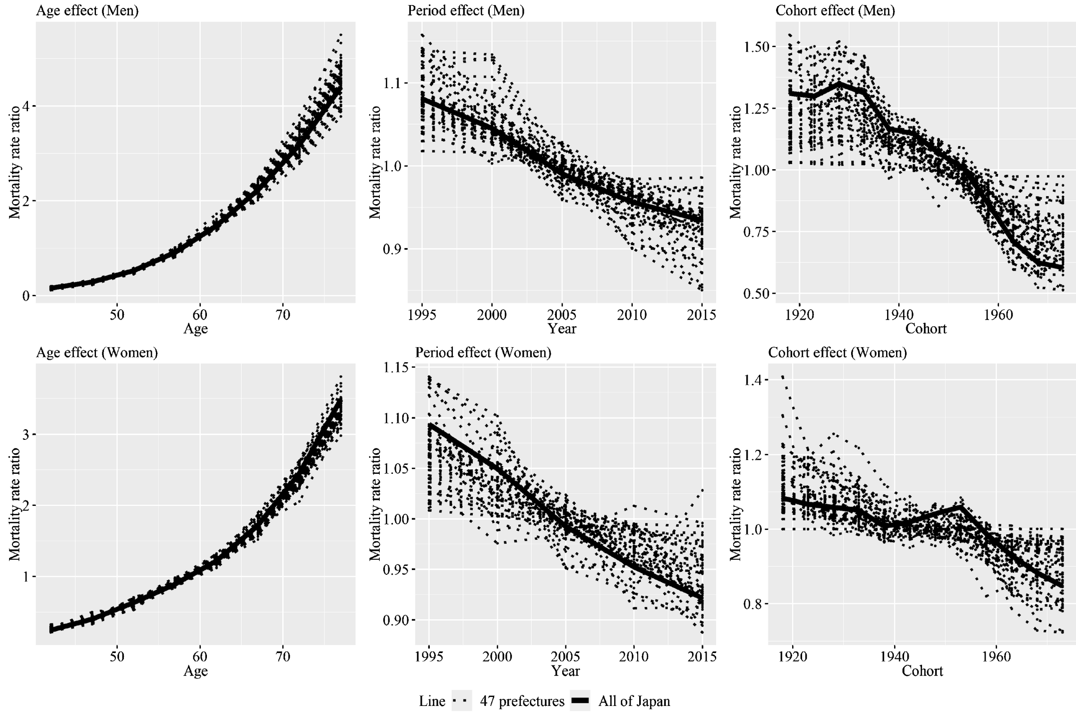
Figure 1 presents the mortality rate ratio by each age, period, and cohort for men and women in 47 Japanese prefectures and all of Japan. The effect of age on the mortality rate increased with increasing age in all prefectures for men. Although the period effect for

Table 1　Age-standardized cancer mortality rates for prefectures for the period of 1995–2015

Prefecture	Men						Women					
	1995	2000	2005	2010	2015	Rate*	1995	2000	2005	2010	2015	Rate*
Hokkaido	456.1	431.0	399.6	364.9	343.8	24.6	231.0	216.4	212.0	208.5	208.5	9.8
Aomori	486.1	476.4	445.7	412.3	384.0	21.0	233.9	206.7	210.1	222.7	215.8	7.7
Iwate	406.4	385.4	372.5	344.3	309.5	23.9	216.1	196.6	192.8	191.8	191.6	11.3
Miyagi	433.5	396.9	358.6	325.0	301.0	30.6	235.1	216.6	199.6	190.8	181.2	22.9
Akita	462.1	461.9	405.4	388.1	348.1	24.7	235.5	225.6	194.1	193.9	202.9	13.8
Yamagata	410.5	416.6	347.7	324.7	285.6	30.4	211.6	213.6	198.0	177.5	163.9	22.5
Fukushima	430.6	407.7	367.5	341.8	304.9	29.2	206.0	203.2	198.7	188.0	186.9	9.3
Ibaraki	427.6	406.8	378.1	335.5	319.2	25.4	218.3	213.3	204.7	189.9	186.6	14.5
Tochigi	425.6	410.5	367.8	333.5	294.0	30.9	216.6	218.0	203.1	197.4	174.9	19.3
Gunma	393.9	372.0	357.7	326.6	290.7	26.2	217.4	207.4	199.2	193.9	169.7	21.9
Saitama	424.6	407.7	371.0	328.9	301.4	29.0	234.8	224.7	212.4	193.7	185.1	21.2
Chiba	434.4	396.8	366.1	313.8	293.4	32.5	226.3	213.5	203.2	195.8	179.1	20.9
Tokyo	446.4	413.1	369.6	338.6	302.3	32.3	248.1	237.2	216.3	201.1	190.4	23.3
Kanagawa	438.8	399.2	356.0	323.7	293.2	33.2	245.5	223.3	208.1	195.9	189.4	22.8
Niigata	433.4	422.5	382.7	338.2	302.8	30.1	226.1	200.7	195.1	167.8	168.5	25.5
Toyama	417.4	386.0	357.5	320.9	312.6	25.1	214.0	202.2	182.0	176.8	168.6	21.2
Ishikawa	420.9	402.4	351.8	336.4	300.5	28.6	219.2	209.8	197.6	184.6	187.2	14.6
Fukui	393.3	359.5	329.7	300.1	267.6	32.0	205.7	197.6	195.4	177.2	176.9	14.0
Yamanashi	400.5	381.4	360.1	324.9	275.0	31.3	222.0	191.1	182.5	159.9	182.6	17.7
Nagano	344.7	332.9	299.2	264.6	232.0	32.7	195.0	184.6	178.3	162.4	156.0	20.0
Gifu	393.4	397.7	336.3	311.1	294.0	25.3	238.1	228.8	196.0	185.7	180.9	24.0
Shizuoka	413.3	388.2	345.2	317.0	284.4	31.2	205.0	202.9	189.8	190.0	171.3	16.4
Aichi	432.7	394.8	364.1	335.1	287.6	33.5	233.8	226.3	206.7	196.0	187.2	19.9
Mie	400.6	395.3	336.1	317.7	298.3	25.5	212.4	208.4	192.3	171.0	173.7	18.2
Shiga	412.9	397.3	350.5	311.4	263.3	36.2	228.4	207.9	203.2	174.7	168.6	26.2
Kyoto	441.1	420.4	364.0	332.2	289.6	34.3	224.0	232.1	206.4	202.3	181.0	19.2
Osaka	515.5	469.8	419.6	366.6	336.1	34.8	266.2	247.5	225.0	209.0	195.9	26.4
Hyogo	489.7	445.0	402.7	356.3	302.7	38.2	244.3	226.9	210.2	192.0	184.6	24.4
Nara	456.3	419.9	395.3	333.8	285.7	37.4	227.7	204.9	197.3	196.0	172.0	24.4
Wakayama	482.8	444.6	404.4	375.5	323.2	33.1	211.2	227.5	207.4	205.3	182.7	13.5
Tottori	498.4	434.5	389.6	380.8	348.9	30.0	222.5	214.8	210.2	206.9	181.7	18.3
Shimane	436.8	434.1	401.4	326.9	324.1	25.8	226.6	183.5	192.6	181.5	163.0	28.1
Okayama	411.5	385.8	336.4	326.2	292.2	29.0	213.8	202.1	172.4	174.2	157.5	26.3
Hiroshima	460.5	422.9	377.4	329.6	286.0	37.9	223.9	199.6	196.3	179.9	169.4	24.3
Yamaguchi	468.6	425.4	402.7	346.5	305.1	34.9	219.5	225.3	202.3	198.3	191.3	12.8
Tokushima	433.2	408.5	356.6	331.1	296.2	31.6	218.4	212.4	191.2	188.0	165.3	24.3
Kagawa	397.3	394.6	347.2	314.6	300.5	24.4	209.4	214.2	189.1	191.3	172.9	17.4
Ehime	425.1	416.7	359.0	356.9	320.1	24.7	205.1	213.9	198.7	180.2	170.6	16.8
Kochi	421.8	379.1	400.3	364.5	329.4	21.9	198.4	197.0	197.5	184.7	178.0	10.3
Fukuoka	507.2	452.8	419.9	363.3	321.8	36.5	248.3	237.3	220.1	202.0	196.1	21.0
Saga	495.5	462.6	427.4	359.4	314.0	36.6	244.5	227.3	223.1	195.1	181.1	25.9
Nagasaki	483.6	453.1	413.7	344.5	312.4	35.4	256.0	222.2	204.8	199.4	189.9	25.8
Kumamoto	397.5	361.1	330.6	307.6	280.2	29.5	208.2	204.4	187.7	181.3	164.7	20.9
Oita	412.0	381.4	336.8	321.6	271.6	34.1	211.7	201.0	173.3	168.5	167.3	21.0
Miyazaki	399.9	401.1	345.0	327.8	306.0	23.5	213.5	200.6	188.4	189.5	178.3	16.5
Kagoshima	417.2	418.4	368.1	323.1	302.0	27.6	209.4	204.4	186.6	186.2	176.2	15.9
Okinawa	405.3	375.6	330.1	298.1	282.5	30.3	201.3	187.1	191.3	181.6	175.0	13.1

* Decreasing rate of age-standardized cancer mortality rates from 1995 to 2015

Figure 1. Results of age-period-cohort analysis of cancer mortality rates in 47 Japanese prefectures and all of Japan.



men tended to decrease over time in all prefectures, the percentage decrease of the effect differed by prefecture. The percentage decrease of the cohort effect was larger than that of the period effect, and the percentage decrease differed by prefecture. The overall percentage decrease of the period effects was larger for women than for men. Conversely, the overall percentage decrease of the cohort effect was smaller for women than for men.

Regarding the results of the goodness-of-fit for the models, the smaller the deviance information criterion (DIC), the higher the goodness-of-fit. For men, the DIC of the models were as follows: Age model, 356.89; Age-period model, 346.86; Age-cohort model, 338.41; Age-period-cohort model, 339.16. For women, the DIC of the models were as follows: Age model, 329.42; Age-period model, 320.82; Age-cohort model, 319.41; Age-period-cohort model, 318.80. For men, the DIC for the age-cohort model was the smallest; for women, the age-period-cohort model was the smallest. Therefore, it is meaningful to analyze the data using a model that takes cohort effects into consideration.

Table 2 depicts the percentage decreases of the cohort effect on cancer mortality rates by prefecture between cohorts born in 1916–1920 and 1971–1975. The prefecture with the largest percentage decrease was Hiroshima, followed by Hyogo, which is in line with the results of Table 1. Conversely, Akita had the smallest percentage decrease of the cohort effect, followed by Kagoshima. Among women, the prefecture with the largest percentage decrease was Miyagi, followed by Shiga, which is not in line with our results in Table 1. Meanwhile, the smallest percentage decrease in the effect among women was noted for Oita, followed by Fukushima. Many prefectures with large percentage decreases in the cohort effect have a government ordinance-designated municipality, whereas most prefectures with small percentage decreases do not, particularly for men. Government ordinance-designated municipalities are municipalities designated by Cabinet order that have a population of more than 500 thousand[13].

Figure 2 demonstrates the scatter plot of the rate of decrease of the cohort effect on cancer mortality rate between cohorts born between 1916 and 1920 and between 1971 and 1975, as well as the mean population size of the prefectures from 1995 to 2015. Spearman's correlation coefficient between the mean population size of prefectures from 1995 to 2015 and the percentage decrease in the cohort effect was 0.370 ($P=0.011$) for men versus 0.182 ($P=0.221$) for women.

Table 3 presents the cancer mortality rate ratio for each prefecture relative to the all of Japan for men. The order shown in Table 3 is same as the rank of the percentage decrease of the cohort effect on cancer mortality rates shown in Table 2. The mortality rate ratio between each prefecture and all of Japan varied by cohort. Although the mortality rate for people born in 1916–1950 in Hiroshima or Hyogo exceeded the all of Japan, that for people born in 1956–1975 in Hyogo or Hiroshima was smaller than the all of Japan. Similarly, although the mortality rate for people born in

Table 2　The rates of decrease of the cohort effect on cancer mortality rate by prefecture between cohorts born in 1916–1920 and 1971–1975

Rank	Men		Women		Rank	Men		Women	
	Prefecture	Decreasing rate*	Prefecture	Decreasing rate*		Prefecture	Decreasing rate*	Prefecture	Decreasing rate*
1	Hiroshima†	0.656	Miyagi†	0.484	25	Tochigi	0.424	Gunma	0.192
2	Hyogo†	0.650	Shiga	0.395	26	Mie	0.409	Shizuoka†	0.187
3	Fukui	0.624	Tottori	0.380	27	Kumamoto†	0.408	Miyazaki	0.173
4	Tokyo†	0.592	Osaka†	0.350	28	Kagawa	0.395	Yamagata	0.165
5	Fukuoka†	0.585	Tokyo†	0.344	29	Tottori	0.368	Hokkaido†	0.161
6	Yamaguchi	0.574	Kanagawa†	0.323	30	Ehime	0.365	Toyama	0.143
7	Shiga	0.566	Chiba†	0.313	31	Kochi	0.363	Iwate	0.136
8	Miyagi†	0.554	Fukuoka†	0.305	32	Chiba†	0.342	Nara	0.133
9	Nagasaki	0.550	Ehime	0.274	33	Okayama†	0.333	Hyogo†	0.115
10	Kyoto†	0.542	Kagawa	0.272	34	Hokkaido†	0.331	Ibaraki	0.114
11	Osaka†	0.531	Yamanashi	0.260	35	Saga	0.316	Wakayama	0.110
12	Aichi†	0.530	Saitama†	0.251	36	Fukushima	0.312	Okinawa	0.110
13	Shizuoka†	0.526	Mie	0.250	37	Aomori	0.305	Yamaguchi	0.108
14	Nagano	0.510	Nagasaki	0.246	38	Ibaraki	0.305	Ishikawa	0.108
15	Kanagawa†	0.501	Niigata†	0.229	39	Yamanashi	0.290	Akita	0.105
16	Nara	0.494	Aichi†	0.223	40	Shimane	0.250	Kagoshima	0.104
17	Tokushima	0.491	Saga	0.222	41	Iwate	0.201	Okayama†	0.095
18	Okinawa	0.483	Shimane	0.218	42	Toyama	0.201	Gifu	0.095
19	Gunma	0.452	Nagano	0.215	43	Miyazaki	0.182	Aomori	0.086
20	Saitama†	0.449	Hiroshima†	0.213	44	Gifu	0.150	Kochi	0.082
21	Ishikawa	0.445	Tokushima	0.207	45	Yamagata	0.149	Kyoto†	0.079
22	Wakayama	0.444	Kumamoto†	0.205	46	Kagoshima	0.088	Fukushima	0.064
23	Oita	0.444	Fukui	0.202	47	Akita	0.056	Oita	−0.001
24	Niigata†	0.435	Tochigi	0.194					

* Decreasing rate of the cohort effect

† Prefectures that have government ordinance-designated municipalities in 2015 or Tokyo

Figure 2.　Scatter plot showing the rate of decrease of the cohort effect on cancer mortality rate and population among prefectures.

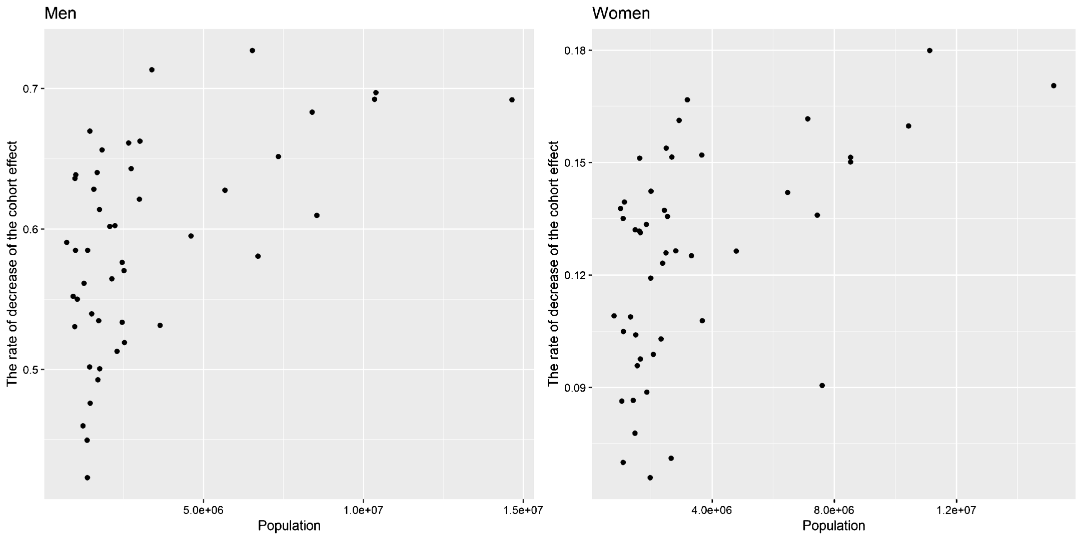


Table 3　Ratio of cancer mortality rates between prefectures and all of Japan by birth cohort among men

Prefecture	Cohort											
	1916–1920	1921–1925	1926–1930	1931–1935	1936–1940	1941–1945	1946–1950	1951–1955	1956–1960	1961–1965	1966–1970	1971–1975
Hiroshima*	1.151	1.130	1.138	1.102	1.091	1.001	1.026	0.983	0.903	0.944	0.845	0.859
Hyogo*	1.213	1.159	1.152	1.136	1.117	1.073	1.073	1.003	0.970	0.923	0.959	0.921
Fukui	0.906	0.917	0.864	0.906	0.893	0.829	0.913	0.847	0.952	0.904	0.822	0.739
Tokyo*	1.055	1.029	0.986	0.996	1.011	1.035	1.019	1.001	0.929	0.926	0.911	0.934
Fukuoka*	1.330	1.266	1.233	1.254	1.108	1.098	1.031	1.041	1.014	0.946	1.054	1.198
Yamaguchi	1.164	1.118	1.100	1.086	1.109	1.100	1.057	1.023	0.925	0.918	0.984	1.076
Shiga	1.006	0.971	1.004	0.967	0.865	0.932	0.821	0.832	0.830	0.945	0.938	0.947
Miyagi*	0.993	1.020	0.971	0.933	0.929	0.953	0.994	0.990	1.018	0.958	1.054	0.959
Nagasaki	1.237	1.243	1.262	1.190	1.123	1.130	1.037	1.082	1.062	1.001	1.072	1.207
Kyoto*	1.076	0.973	0.989	0.976	0.955	0.949	0.976	1.001	0.926	0.917	1.003	1.069
Osaka*	1.049	1.125	1.131	1.096	1.085	1.090	1.135	1.107	1.083	1.080	1.076	1.067
Aichi*	0.978	0.926	0.908	0.953	0.955	0.978	0.959	0.903	0.942	0.958	1.009	0.998
Shizuoka*	0.948	0.942	0.988	1.005	0.966	0.906	0.883	0.891	0.888	0.878	0.851	0.974
Nagano	0.775	0.773	0.768	0.774	0.790	0.813	0.768	0.774	0.773	0.866	0.846	0.824
Kanagawa*	0.898	0.900	0.909	0.898	0.948	0.952	0.989	0.961	0.968	0.935	0.993	0.971
Nara	1.033	1.030	1.041	1.047	0.961	0.931	0.949	0.968	1.035	1.072	1.126	1.134
Tokushima	0.979	1.015	1.024	1.016	0.982	1.003	1.050	0.955	0.972	1.065	1.127	1.079
Okinawa	1.104	1.139	0.961	0.878	0.816	0.875	0.787	0.954	0.950	1.201	1.044	1.238
Gunma	0.852	0.887	0.903	0.926	0.926	0.930	0.870	0.866	0.898	1.042	1.046	1.012
Saitama*	0.932	0.924	0.946	0.927	0.943	0.937	0.960	0.986	1.009	1.030	1.099	1.114
Ishikawa	0.904	0.963	0.918	0.921	0.925	0.965	0.984	0.996	1.039	1.071	1.111	1.088
Wakayama	1.028	1.098	1.029	1.068	1.057	0.992	1.043	0.989	0.970	1.078	1.235	1.238
Oita	0.915	0.884	0.855	0.833	0.894	0.940	0.968	0.986	1.042	1.030	1.080	1.103
Niigata*	0.977	0.997	0.969	0.977	0.997	1.044	0.992	1.043	1.081	1.131	1.179	1.198
Tochigi	0.904	0.922	0.943	0.936	0.945	0.928	0.867	0.855	0.966	1.134	1.171	1.128
Mie	0.794	0.836	0.838	0.874	0.861	0.901	0.985	0.973	0.992	1.119	1.104	1.017
Kumamoto*	0.863	0.874	0.917	0.872	0.911	0.899	0.906	0.897	0.942	1.020	1.147	1.108
Kagawa	0.936	0.965	0.952	0.971	0.928	0.911	0.975	0.911	0.996	1.091	1.148	1.228
Tottori	1.055	1.083	1.063	1.023	1.178	1.176	1.227	1.164	1.218	1.380	1.446	1.446
Ehime	0.950	0.994	1.011	1.015	1.013	1.019	1.060	1.107	1.078	1.248	1.270	1.308
Kochi	0.948	0.910	0.905	0.887	1.027	1.042	1.110	1.161	1.133	1.259	1.324	1.309
Chiba*	0.854	0.859	0.889	0.902	0.931	0.935	0.962	0.993	1.051	1.126	1.194	1.218
Okayama*	0.886	0.915	0.905	0.942	0.953	0.948	0.937	0.919	0.969	1.058	1.281	1.283
Hokkaido*	0.923	0.941	0.955	0.966	1.061	1.069	1.085	1.116	1.170	1.271	1.364	1.338
Saga	0.996	1.010	1.009	1.011	1.083	1.047	1.045	1.100	1.184	1.376	1.489	1.477
Fukushima	0.965	0.962	0.956	0.956	0.976	0.969	0.996	0.982	1.070	1.258	1.339	1.440
Aomori	1.076	1.060	1.057	1.079	1.186	1.175	1.178	1.256	1.360	1.536	1.607	1.621
Ibaraki	0.857	0.899	0.905	0.922	0.937	0.917	0.968	0.990	1.072	1.197	1.283	1.292
Yamanashi	0.851	0.875	0.851	0.864	0.933	0.891	0.945	0.945	1.035	1.135	1.290	1.309
Shimane	0.869	0.905	0.889	0.900	0.979	1.022	1.001	1.046	1.118	1.284	1.404	1.413
Iwate	0.863	0.881	0.867	0.847	0.917	0.922	0.966	1.039	1.159	1.367	1.485	1.495
Toyama	0.839	0.870	0.823	0.848	0.943	0.926	0.937	0.931	1.034	1.191	1.371	1.452
Miyazaki	0.852	0.890	0.850	0.872	0.904	0.903	0.955	0.979	1.104	1.286	1.458	1.510
Gifu	0.734	0.744	0.736	0.791	0.854	0.842	0.912	0.927	1.060	1.221	1.319	1.352
Yamagata	0.811	0.830	0.817	0.803	0.862	0.878	0.919	0.971	1.099	1.302	1.479	1.498
Kagoshima	0.837	0.844	0.814	0.838	0.914	0.935	1.013	1.081	1.235	1.446	1.619	1.655
Akita	0.935	0.936	0.898	0.926	1.025	1.031	1.109	1.177	1.351	1.627	1.852	1.914

* Prefectures that have government ordinance-designated municipalities in 2015 or Tokyo

Table 4 Ratio of cancer mortality rates between prefectures and all of Japan by birth cohort among women

Prefecture	Cohort											
	1916–1920	1921–1925	1926–1930	1931–1935	1936–1940	1941–1945	1946–1950	1951–1955	1956–1960	1961–1965	1966–1970	1971–1975
Miyagi*	1.292	1.130	0.999	1.071	1.054	1.061	0.948	0.867	0.967	0.917	0.854	0.853
Shiga	1.025	1.037	1.101	1.076	1.032	0.976	0.901	0.855	0.881	0.786	0.766	0.793
Tottori	1.203	1.035	0.976	0.998	0.958	1.018	0.967	1.023	1.002	0.937	0.942	0.954
Osaka*	1.232	1.181	1.179	1.153	1.109	1.095	1.081	1.065	1.000	0.979	0.977	1.023
Tokyo*	1.150	1.145	1.116	1.084	1.082	1.049	1.069	1.043	0.994	0.934	0.960	0.964
Kanagawa*	1.117	1.127	1.103	1.033	1.011	1.016	0.983	1.022	0.972	0.983	0.984	0.966
Chiba*	1.059	1.117	1.105	1.084	1.043	1.028	0.989	0.963	0.929	0.886	0.888	0.930
Fukuoka*	1.148	1.186	1.175	1.122	1.073	1.052	1.031	1.013	1.027	0.964	0.979	1.020
Ehime	0.963	0.971	0.983	0.969	0.993	0.954	0.947	0.966	0.982	0.934	0.897	0.893
Kagawa	0.958	1.019	1.001	0.976	1.014	0.977	0.916	0.932	0.889	0.832	0.858	0.891
Yamanashi	0.992	1.016	1.059	0.987	0.953	0.964	0.902	0.829	0.771	0.853	0.920	0.938
Saitama*	1.090	1.062	1.050	1.014	1.029	1.026	1.027	1.005	0.970	0.990	1.001	1.045
Mie	0.965	0.960	1.017	0.978	0.968	0.941	0.971	0.898	0.907	0.905	0.926	0.924
Nagasaki	1.245	1.215	1.186	1.096	1.072	1.030	1.042	1.014	1.022	1.054	1.110	1.199
Niigata*	1.008	0.989	0.918	0.944	0.974	0.952	0.923	0.937	0.940	0.948	0.979	0.993
Aichi*	0.999	1.026	1.023	1.025	1.024	1.004	1.021	0.971	0.990	1.000	0.999	0.992
Saga	1.092	1.135	1.108	1.121	1.092	1.037	1.005	0.939	0.979	1.042	1.061	1.086
Shimane	0.935	0.949	0.963	0.962	1.000	0.967	0.939	0.894	0.901	0.905	0.908	0.935
Nagano	0.866	0.869	0.898	0.893	0.884	0.839	0.816	0.809	0.830	0.836	0.855	0.869
Hiroshima*	0.935	0.942	0.970	0.983	0.982	0.926	0.907	0.853	0.859	0.915	0.914	0.941
Tokushima	0.983	0.998	0.950	0.966	0.999	0.976	0.922	0.880	0.910	0.943	0.966	0.997
Kumamoto*	0.990	0.965	0.925	0.910	0.929	0.907	0.903	0.897	0.938	0.985	0.991	1.006
Fukui	0.953	0.983	0.960	0.919	0.927	0.907	0.872	0.813	0.844	0.879	0.941	0.971
Tochigi	1.064	1.039	0.975	0.989	0.997	0.967	0.925	0.954	1.025	1.037	1.040	1.095
Gunma	0.964	0.984	0.985	0.945	0.962	0.955	0.921	0.914	0.973	0.971	0.957	0.996
Shizuoka*	0.951	0.922	0.946	0.941	0.956	0.950	0.912	0.915	0.975	0.967	0.947	0.987
Miyazaki	0.989	0.998	1.002	0.958	0.995	0.946	0.922	0.935	0.974	0.986	0.985	1.045
Yamagata	0.958	0.961	0.959	0.980	0.953	0.934	0.894	0.870	0.909	0.944	0.972	1.023
Hokkaido*	1.079	1.076	1.040	1.029	1.030	1.070	1.069	1.040	1.046	1.094	1.137	1.157
Toyama	0.929	0.938	0.927	0.913	0.949	0.925	0.889	0.878	0.902	0.964	0.995	1.018
Iwate	1.010	0.993	0.949	0.939	0.978	0.985	0.976	0.953	1.002	1.042	1.091	1.116
Nara	0.971	0.988	0.999	0.987	0.991	0.971	0.941	0.909	0.954	1.004	1.051	1.077
Hyogo*	1.001	0.986	1.006	0.985	1.006	0.992	0.975	0.960	1.012	1.049	1.094	1.132
Ibaraki	0.999	1.005	0.999	1.008	1.020	1.005	0.995	0.953	1.031	1.085	1.108	1.131
Wakayama	1.022	1.041	1.025	0.997	0.993	1.007	0.993	0.966	1.012	1.101	1.141	1.162
Okinawa	0.965	0.963	0.933	0.916	0.924	0.930	0.890	0.896	0.940	0.977	1.039	1.098
Yamaguchi	1.031	1.020	1.000	0.982	1.010	0.991	0.991	0.982	1.046	1.079	1.122	1.175
Ishikawa	0.929	0.940	0.943	0.930	0.982	0.949	0.931	0.902	0.940	0.983	1.023	1.059
Akita	1.068	1.085	1.042	1.030	1.048	1.037	1.029	1.004	1.046	1.123	1.188	1.222
Kagoshima	0.978	0.977	0.955	0.951	0.968	0.959	0.928	0.895	0.963	1.022	1.075	1.121
Okayama*	0.884	0.894	0.897	0.917	0.924	0.897	0.880	0.853	0.909	0.950	0.996	1.022
Gifu	0.978	0.987	0.996	0.998	1.022	1.000	0.975	0.963	1.010	1.039	1.088	1.131
Aomori	1.078	1.062	1.025	1.047	1.059	1.052	1.047	1.076	1.129	1.199	1.230	1.259
Kochi	0.902	0.932	0.910	0.909	0.957	0.919	0.885	0.855	0.919	0.968	1.019	1.058
Kyoto*	0.940	0.955	0.972	0.959	0.992	0.973	0.962	0.941	0.994	1.047	1.082	1.107
Fukushima	0.942	0.949	0.941	0.951	0.979	0.950	0.915	0.894	0.961	1.032	1.084	1.127
Oita	0.843	0.856	0.863	0.870	0.907	0.897	0.878	0.863	0.925	0.984	1.036	1.079

* Prefectures that have government ordinance-designated municipalities in 2015 or Tokyo

1916–1935 in Akita or Kagoshima was smaller than the nationwide average, the mortality rate for people born in 1946–1975 in Akita or Kagoshima exceeded the all of Japan.

Table 4 presents cancer mortality rate ratios between each prefecture and the all of Japan for women. The order shown in Table 4 is same as the rank of the percentage decrease of the cohort effect on cancer mortality rates shown in Table 2. The mortality rate ratio exceeded 1 for all examined cohorts in Aomori, Akita, Hokkaido, and Nagasaki. Meanwhile, although the estimates of ratios were less than 1 for Kochi, Kyoto, Fukushima, and Kochi for people born in 1916–1960, the ratios exceeded 1 for these prefectures for people born in 1966–1975.

IV. DISCUSSION

Although the disparity in age-standardized cancer mortality rates among prefectures is often considered, the percentage decreases in age-standardized cancer mortality rates also vary greatly among prefectures. The age-standardized mortality rates and the percentage decrease are not necessarily correlated. The trends of the mortality rate ratio over time and by cohort differed among the prefectures. The overall percentage decrease of the cohort effect was larger for men than for women. Conversely, the overall percentage decrease of the period effect was larger for women. Therefore, it is considered that the decline of cancer mortality rates for men is mainly attributable to decreases of the cohort effect, and the variation of the decline in mortality rates over time is mainly associated with the difference in the decrease of cohort effects. Conversely, the disparities of mortality rates among prefectures for women were attributable to both period and cohort effects because the overall decreases of the period and cohort effects were relatively similar. In addition, the difference in the percentage decrease of cohort effects by sex is considered to be related to cancer mortality rates.

It has already been shown that representative cancer types (ie, lung, stomach, colorectal, and liver cancer) were also decreasing among the cohorts[14]. In particular, the mortality rate for stomach and liver cancer among patients aged 40 to 80 years decreased significantly from 1995 to 2015. During the same time, the cohort effects also decreased over the cohorts[14]. Therefore, there is a possibility that decreasing rate of the cohort effects for stomach and liver cancer largely varied among prefectures. Also, the mortality rate for breast cancer is increasing in the middle and older age groups for women[3]; the trend of cohort effects on breast cancer mortality rate might also differ among prefectures. Although we analyzed the data for mortality, decreasing rates of cohort effects on the incidence rate of cancer are thought to also vary among prefectures because the trends of cohort effects on incidence rate and mortality rate were rather similar in a previous study in Japan[6]. The age-standardized incidence rate of stomach and liver cancers in Yamagata, Fukui, and Nagasaki was shown to have decreased over the years, and it is considered to be related to a decrease in infection-related factors (ie, *Helicobacter pylori* and hepatitis virus)[15]. Therefore, there is a possibility that degree of immunization of hepatitis virus or removal of *H. pylori* vary considerably among prefectures.

Regarding other factors that might be related to the differences in the magnitude of the decrease of the cohort effect, particularly for men, differences in lifestyle changes among cohorts could be one explanation. Several previous studies investigated health disparities among prefectures[16~20]. As factors explaining differences in mortality rates among prefectures, lifestyle habits such as smoking, drinking, and salt intake are often cited. It was reported that smoking rates vary among prefectures, and age-standardized smoking rates decreased from 2001 to 2010 for men[21]. Differences in the percentage decrease of smoking rates among cohorts are considered to be related to the percentage decreases of cancer mortality rates. Therefore, it will be meaningful to conduct an APC analysis of smoking habits by prefecture similarly as performed this study. It was also revealed that age-standardized heavy drinking rates decreased from 2013 to 2016 among men[22], and the magnitude of the decrease of the cohort effect for heavy drinking rates might vary by prefecture. In addition, prefectures that have a government ordinance-designated municipality or Tokyo tended to be of a higher rank in the decreasing rates, and there was a positive correlation between population size and the percentage decrease of the cohort effect for men. One possible explanation is that there is a disparity in the decreasing rates between government ordinance-designated municipalities and other areas. Government ordinance-designated municipalities can be classified as urban areas in Japan because these cities have more than 500,000 citizens. Several reports identified differences in the levels of physical activity between urban and rural areas[23,24]. In Japan, it has been demonstrated that the size of a city was proportion to the total number of daily steps[25], and the changes of the cohort effect on exercise habits could differ between urban and rural areas.

There are some limitations in this study. First, we analyzed the data of all-sites cancer, but we did not analyze specific types of cancer. By analyzing the data for each type of cancer, we could assess the difference between a prefecture and all of Japan for specific cancer types. Also, we could assess the possible risk factors that affect the change of cohort effect in more detail. Therefore, studies focusing on specific types of cancer should be conducted in the future. Second, although we analyzed the data for each prefecture, by analyzing the data for municipalities, we can grasp the urban-rural differences in cancer mortality rates more accurately.

Finally, we found that the relative rankings of the prefectures differed by cohort. Therefore, assessment of the risk of cancer for people based on the cohort where a person was born may be needed, particularly for men. A high cancer mortality rate in a cohort was not always related to a high age-standardized mortality rate of a prefecture. Each prefecture must identify the target cohorts with mortality rate exceeding the all of Japan to implement specific countermeasures against cancer. In addition, each prefecture must assess lifestyle differences among cohorts to develop strategies to reduce cancer mortality rates.

V. CONCLUSION

The percentage decrease of cohort effects on cancer mortality rates varied greatly among prefectures, particularly for men, and there was a positive correlation between the population size of a prefecture and the percentage decrease for men. In addition, changes in cancer mortality rates were strongly affected by birth cohort. Each prefecture must identify the target cohorts with higher than average mortality rates to enact specific countermeasures against cancer.

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