International Journal of Epidemiology, 2024, **53(2)**, dyae031
https://doi.org/10.1093/ije/dyae031
Original Article

IEA
International Epidemiological Association
OXFORD

Original Article

Educational inequalities in all-cause and cause-specific mortality in Japan: national census-linked mortality data for 2010–15

Hirokazu Tanaka ,[1,*] **Kota Katanoda** ,[1] **Kayo Togawa**[1] **and Yasuki Kobayashi**[2]

[1]Division of Population Data Science, Institute for Cancer Control, National Cancer Center, Tokyo, Japan and [2]Department of Public Health, Graduate School of Medicine, The University of Tokyo, Tokyo, Japan

*Corresponding author. Division of Population Data Science, National Cancer Center Institute for Cancer Control, 5-1-1, Tsukiji, Chuo-ku, Tokyo 104-0045, Japan. E-mail: hitanak@ncc.go.jp

Abstract

Background: Due to the lack of a national mortality inequality monitoring framework, the overall picture in Japan remains unclear. Here, we investigated educational inequalities in mortality and their cause-specific contribution in Japan.

Method: Data were obtained by linking the 2010 Japanese population census and death records between 1 October 2010 and 30 September 2015. We included 7 984 451 Japanese people aged 30–79 years who had a unique 'matching key' generated by sex, birth year/month, address (municipality), marital status and age of spouse (9.9% of the total census population). We computed population-weighted all-cause and cause-specific age-standardized mortality rates (ASMRs) by education level. In addition, we calculated the slope index of inequality (SII), relative index inequality (RII) by education level, and population attributable fraction (PAF) referenced with the highest education (e.g. university graduation).

Results: Individuals with less education had higher all-cause and cause-specific ASMRs than highly educated individuals. All-cause SII (per 100 000 person-years) values were 433 (95% CI: 410–457) for men and 235 (95% CI: 217–252) for women. RII values were 1.48 (95% CI: 1.45–1.51) for men and 1.47 (95% CI: 1.43–1.51) for women. Estimated PAFs, excess premature deaths caused by educational inequalities, were 11.6% for men and 16.3% for women, respectively. Cerebrovascular diseases, ischaemic heart diseases and lung cancer were the major contributors to mortality inequalities for both sexes.

Conclusions: This first census-based comprehensive report on cause-specific educational mortality inequalities suggested that differences in unfavourable health risk factors by educational background might be associated with these inequalities in Japan.

Keywords: Health inequalities, age-standardized mortality, cause-specific death, Japan, socioeconomic status, deterministic linkage.

Key Messages

- Although socioeconomic inequalities in mortality are reported to be substantial in most high-income countries, the overall picture remains unclear in Japan due to the lack of a national mortality inequality monitoring framework.
- This is the first study to comprehensively report all-cause and cause-specific educational mortality inequalities in Japan, by linking the national census to mortality data for 2010–15 using our unique method.
- Individuals with the lowest education had about 40% higher premature all-cause mortality risk than the highest educated individuals in Japan.
- We found substantial cause-specific age-standardized mortality rate differences across educational levels, as evidenced by the slope index of inequality and relative index inequality.
- The cause-specific patterns suggest that differences by educational background in unfavourable health risk factors might be associated with these results in Japan, where health and health care are considered excellent in general.

Introduction

Socioeconomic status (e.g. educational level, occupational class and income level) is a major social determinant of illness and premature mortality worldwide. Reducing health inequalities is an important global issue, supported by careful monitoring and assessment.[1] Ongoing monitoring has revealed that socioeconomic inequalities in mortality are substantial in most high-income countries, including European countries,[2–5] the USA,[6] Canada,[7] Australia[8,9] and New Zealand.[10] Moreover these analyses, generally conducted using national census-linked mortality data, serve as the basis of policy making and evaluations.

However, evidence for mortality inequalities and their cause-specific contributions has been scarce in Japan, a

Received: 13 June 2023. **Editorial Decision:** 18 January 2024. **Accepted:** 13 February 2024

country with comparatively high health levels (e.g. long life expectancy) and universal health care, characterized by a traditionally fish-eating culture, low obesity rate and positive attitude toward sanitary behaviour.[11] Few studies have reported on nationwide health inequalities in Japan, although relatively small health inequalities have been suggested at the localized population level.[12] Lessons from Japan's achievement of outstanding long-term mortality reductions[11] and the development of an attentive medical care system over a half-century[13] will likely provide clues for reducing global health inequalities.

Japan's national health initiative, 'Health Japan 21 (the second term)' has since 2013 included the goal of reducing health inequalities.[14] Nevertheless, no national health inequality monitoring framework or detailed target values to guide plans and actions have yet been developed. As one solution, we have promoted the identification of socioeconomic inequalities in health in Japan using a nationally representative health survey, in addition to developing national census-linked mortality data.[15] Previous research has clarified widening inequalities in smoking,[16] substantial inequalities in self-rated health[17,18] and mortality inequalities by occupational class.[19,20] The overall picture of educational inequalities in all-cause and cause-specific mortality, commonly assessed internationally, remains unclear in Japan because of the lack of a national death records linkage system using a unique personalized identification code.

This study aimed to quantify educational mortality differences in all-cause and cause-specific mortality in Japan, to investigate mortality due to inequalities in education.

Methods

Data source

We developed the Japanese national census-linked mortality data between 1 October 2010 and 30 September 2015 (Supplementary Figure S1, available as Supplementary data at *IJE* online).[15] We obtained anonymized microdata from the 2010 Population Census (hereafter, 'the census'),[21] conducted every 5 years by the Ministry of Internal Affairs and Communications, and from death records, which are included in the national vital statistics and collected annually by the Ministry of Health, Labour and Welfare.[22] The method used for data linkage for the Japanese population has been presented in a methodology paper.[15] Briefly, persons who had a unique 'matching key', defined by set of key characteristics, were identified from the census and included as the unique-key sample population. Death records were then linked to the unique-key sample population using a deterministic linkage method. Due to the lack of an official personal identification code in Japan, we previously used five variables as 'matching key', namely sex, birth year, birth month, address (municipality) and marital status.[15] In the current analysis however, we added age of spouse as a 'matching key', which increased the size of the unique-key sample population (the sampling rate increased from 1.9% of the whole Japanese population aged 30–79 years in the previous analysis[15] to 9.9% in the current analysis) and provided more successful linkage. Death records with a unique 'matching key' were then linked to these records using the deterministic linkage method.[15]

The sample population was weighted to adjust the demographics to approximate those of the whole population of Japan.[15] The weighting score was calculated as the ratio representing the number of the whole population having a certain weighting key divided by the number of persons in the unique-key sample.[15] The weighting key consisted of prefecture, sex, 5-year age category, marital status, education level and occupational class (for people aged 30–64 years only). For example, suppose that 50 married women aged 40–44 years who were manual workers, had high school graduation and lived in X prefecture were observed in the census, and 10 women with the same demographics were observed in the unique-key sample population: a weighting score of '5' (= 50/10) would be allocated to each sampled woman.[15]

Finally, we developed three mortality datasets: (i) complete registry mortality data [unlinked but whole population: results (A) in Table 1]; (ii) unweighted unique-key sample population with linked death records; and (iii) population-weighted unique-key sample population with linked death records [results (B) in Table 1].

Mortality calculations

We computed all-cause and cause-specific age-standardized mortality rates (ASMRs) by education level (30–79 years) using each of the mortality datasets. The direct standardized method was used on the basis of the 2015 Japan Standard Population.[23] Mortality estimates calculated by weighted unique-key sample population were compared with complete mortality registry, to assess generalization of mortality.

Education level was classified into three categories: 'low' (elementary school/junior high school graduates); 'middle' (high school graduates); and 'high' (technical professional school graduates/2-year college graduates/university graduates/graduate school graduates).[15,24] Causes of death were classified using the International Classification of Diseases, 10th revision (ICD-10). The underlying causes of death were classified into four broad groups: all cancers [C00-D48], diseases of the circulatory system [I00-I99], external causes (including injuries and suicide) [V01-Y98] and all other diseases.

Inequality measures for educational level

We calculated 'mortality rate ratios', 'slope index of inequality (SII)' and 'relative index inequality (RII)' by educational level as inequality measures. Individuals with 'unknown education levels' were excluded from the primary analysis of the inequality measures; however, the multiple imputation analysis was also performed as sensitivity analysis. We used multiple imputation by chained equations to account for missing values for educational level. The imputation model employed an ordered logistic regression for educational level. The multiple imputation model included the variables of 5-year age category, sex, prefecture, marital status and survival status. The imputation process was repeated 20 times to evaluate the missing data bias.

ASMR ratios comparing low/middle education and high education levels as reference were calculated. The SII and RII were evaluated by cause of death.[25] Population attributable fraction (PAF) by educational level was calculated as follows:

Table 1 Comparison of age-standardized mortality rate (30–79 years old, per 100 000 person-years) between all Japanese population (complete mortality registry) and weighted unique-key sample population during 2010–15[a]

	All population (complete mortality registry)[b] (A)	Weighted unique-key sample population (B)	Comparisons with complete mortality registry	
			Absolute difference (B)–(A)	% difference [(B)–(A)]/(A) (%)
Men (30–79 years old)				
All-cause	1209	1200	–9	–0.8
Broad cause of death (ICD-10)				
All cancer (C00-D48)	489	487	–2	–0.2
Diseases of the circulatory system (I00-I99)	287	288	1	0.1
External causes (V01-Y98)	91	98	7	7.7
Others[c]	343	330	–13	–3.6
Women (30–79 years old)				
All-cause	561	625	64	11.4
Broad cause of death				
All cancer (C00-D48)	235	260	25	10.3
Diseases of the circulatory system (I00-I99)	135	152	17	12.8
External causes (V01-Y98)	41	47	6	15.3
Others[c]	150	169	19	12.3

[a] Age-standardized mortality rates were computed using the 2015 Japan standard population and data in 5-year age intervals.
[b] Data from vital statistics.
[c] All deaths except for 'all cancer', 'diseases of the circulatory system' and 'external causes'.

$$\text{PAF (\%)} = \frac{Pop_{low}*\left(RR_{\frac{low}{high}}-1\right)+Pop_{middle}*\left(RR_{\frac{middle}{high}}-1\right)}{Pop_{low}*\left(RR_{\frac{low}{high}}-1\right)+Pop_{middle}*\left(RR_{\frac{middle}{high}}-1\right)+1}*100 \quad (1)$$

where Pop_i refers to the percentage of weighted population by educational level (low or middle education) and $RR_{i/high}$ refers to ASMR ratios comparing low or middle education and high education levels as reference. Estimated PAF is the fraction of all deaths that would not have occurred if there had been no educational mortality difference.[26] We also calculated cause-specific contributions to the PAF. Finally, the annual number of excess deaths among lower educational level groups (i.e. middle and low education) in Japan was estimated by applying the PAF to the total deaths for Japanese in 2010 from the vital statistics (30–79 years; $n = 345\,778$ for men and 175 168 for women). The number of cause-specific excess deaths by sex was calculated by multiplying the percentage of cause-specific contributions to the PAF and total deaths.

Results

The unique-key sample population

We included 7 984 451 Japanese men ($n = 3\,992\,202$) and women ($n = 3\,992\,249$) aged 30–79 years (9.9% in national census) as the unique-key sample population. All had a unique 'matching key' generated by sex, birth year, birth month, address, marital status and age of spouse. Overall, 325 824 death records (224 538 men and 101 286 women: cumulative number of deaths between 1 October 2010 and 30 September 2015) were linked to the unique-key sample population (linkage rate: 5.6% for men and 2.5% for women). Table 1 confirms the validation of (B) the census-linked mortality (weighted unique-key sample population) compared with (A) the complete mortality. The ASMRs of the weighted unique-key sample population were similar to those of the complete mortality registry for men. For women, the difference in ASMR (per 100 000 person-years) was ∼10-15% for all-cause and cause-specific deaths. Supplementary Tables S1 and S2 (available as Supplementary data at *IJE* online) show detailed demographic statistics and the distribution of populations and mortality rates for men and women, respectively.

All-cause and broad cause-specific mortality

Crude all-cause mortality rates for the high-, middle- and low-educated groups increased in parallel as age increased for both sexes, and were consistent with mortality rates by the complete mortality registry (Supplementary Figure S2, available as Supplementary data at *IJE* online: polygonal line). Table 2 shows the estimated all-cause and broad cause-specific ASMRs by educational level. For men, all-cause ASMRs (per 100 000 person-years) were 1025 (95% CI: 1013–1037) for high education level, 1188 (95% CI: 1179–1197) for middle education level and 1392 (95% CI: 1377–1406) for low education level. For women, all-cause ASMRs were 496 (95% CI: 485–508) for high education level, 613 (95% CI: 607–618) for middle education level and 724 (95% CI: 713–735) for low education level. Thus, the ASMR ratios between low and high education levels for those aged 30–79 years were 1.36 (95% CI: 1.30–1.41) for men and 1.46 (95% CI: 1.32–1.59) for women, whereas the ASMR ratios between middle and high education levels were 1.16 (95% CI: 1.12–1.20) for men and 1.23 (95% CI: 1.11–1.36) for women (shown in Supplementary Figure S1, available as Supplementary data at *IJE* online). All-cause SII (per 100 000 person-years) were 433 (95% CI: 410–457) for men and 235 (95% CI: 217–252) for women. RII were 1.48 (95% CI: 1.45–1.51) for men and 1.47 (95% CI: 1.43–1.51) for women. Broad cause-specific SII (per 100 000 person-years) ranged from 55 (95% CI: 48–62) for external causes to 161 (95% CI: 149–173) for others for men, and from 31 (95% CI: 26–36) for external causes to 84 (95% CI: 75–92) for diseases of the circulatory system for women. Diseases of the circulatory system (e.g. SII: 113 per 100 000 person-years for men) was the main broad group of causes of death driving absolute inequalities and all cancer (e.g. SII: 92 per 100 000

Table 2 Age-standardized mortality rates (30–79 years old, per 100 000 person-years) by educational level and inequality indices during 2010–15[a]

	All-cause		All cancer (C00-D48)		Diseases of the circulatory system (I00-I99)		External causes (V01-Y98)		Others[b]	
	ASMR	95% CI	ASMR	95% CI	ASMR	95% CI	ASMR	95% CI	ASMR	95% CI
Men										
Educational level (30–79 years old)										
High (ISCED 5–8)	1025	1013–1037	448	440–456	236	230–242	80	77–83	266	259–272
Middle (ISCED 3, 4)	1188	1179–1197	493	487–498	280	276–285	98	96–101	320	315–325
Low (ISCED 1, 2)	1392	1377–1406	524	516–532	329	322–336	124	119–129	421	412–429
Inequality indices										
Slope Index of Inequality	433	410–457	92	77–107	113	102–124	55	48–62	161	149–173
Relative Index of Inequality	1.48	1.45–1.51	1.21	1.18–1.25	1.54	1.47–1.60	1.82	1.70–1.95	1.78	1.71–1.85
Women										
Educational level (30–79 years old)										
High (ISCED 5–8)	496	485–508	236	228–243	102	97–108	33	30–35	129	122–135
Middle (ISCED 3, 4)	613	607–618	260	257–264	149	146–152	47	45–49	158	156–161
Low (ISCED 1, 2)	724	713–735	273	266–280	186	180–191	56	52–60	212	206–218
Inequality indices										
Slope Index of Inequality	235	217–252	32	20–43	84	75–92	31	26–36	83	74–92
Relative Index of Inequality	1.47	1.43–1.51	1.11	1.06–1.16	1.81	1.70–1.93	1.88	1.69–2.09	1.75	1.65–1.86

ASMR, age-standardized mortality rate; CI, confidence interval; ISCED, International Standard Classification of Education, Slope Index of Inequality (per 100 000 person-years).

[a] ASMRs were computed using the 2015 Japan standard population and data in 5-year age intervals.

[b] All deaths except for 'all cancer', 'diseases of the circulatory system' and 'external causes'.

person-years for men) was second for both sexes. The sensitivity analysis (multiple imputation analysis for missing values for educational level) showed similar results of ASMR and inequality indices (Supplementary Table S3, available as Supplementary data at *IJE* online) for both sexes to the primary results.

Cause-specific mortality

Table 3 shows cause-specific ASMR (per 100 000 person-years) and inequality indices. Supplementary Table S4 (available as Supplementary data at *IJE* online) shows the detailed ASMRs from cancer. We identified substantial differences (lower mortality risk among higher educational level) in all kinds of cause-specific mortality, except for some cancer sites (e.g. oesophageal cancer, pancreatic cancer, leukaemia and breast cancer) for both sexes. For example, ASMRs from and SII by lung cancer, cerebrovascular diseases and ischaemic heart diseases were relatively higher than other causes. Conversely, breast cancer ASMRs (per 100000 person-years) for individuals with high, middle and low levels of education were 31.0 (95% CI: 28.7–33.2), 30.5 (95% CI: 29.3–31.8) and 25.8 (95% CI: 23.4–28.3) for women, respectively.

Population attributable fraction (PAF) and decomposition

Table 4 shows the percentage of cause-specific contributions to PAF (all-cause), and the estimated number of excess premature deaths. Estimated PAFs (all-cause) by educational level were 11.6% for men and 16.3% for women, respectively, and the estimated cause-specific PAFs are illustrated in Supplementary Figure S3 (available as Supplementary data at *IJE* online). The estimated PAF (all-cause) is equivalent to be 68 662 excess premature deaths in Japanese men and women aged 30–79 years in 2010. Decomposition of the PAF indicated that diseases of the circulatory system (26.4% for men and 38.9% for women; 21 684 excess deaths in total) were a major contributor to educational inequality in all-cause mortality.

Discussion

Main findings

This is the first study to comprehensively report all-cause and cause-specific educational inequalities in mortality in Japan, by linking national census to mortality data for 2010–15 using our unique method. The strength of this study is in applying individual record linkages between administrative data (vital statistics) and the census for about 8 million of the Japanese population. Individuals with the lowest education had about 40% higher premature all-cause mortality risk than the highest educated individuals. We found significant cause-specific ASMR differences across different educational levels, evidenced by SII and RII. In Japan, cerebrovascular diseases, ischaemic heart diseases and lung cancer were important contributors to mortality inequality for both sexes.

Interpretation

The cause-specific patterns suggested that unfavourable health risk factors were more prominent among those with low educational level in Japan, where health and health care are considered excellent in general.[11,13] Mortality from diseases of the circulatory system showed the largest inequalities in Japan, as they also do in European countries.[2] The unfavourable distribution of behavioural risk factors[16] (e.g. smoking) among less educated men and women probably contributed to the increased mortality in this group in the Japanese population, as well as worldwide. In addition, the trend in breast cancer in Japan, with higher mortality among those with higher educational level, is consistent with findings in European countries.[2] This is probably because important risk factors for breast cancer (no birth history, delayed age at childbearing and less breastfeeding) are also frequent among Japanese females in the higher educational level.[27] In contrast, mortality inequalities from cerebrovascular disease in Japan were larger than those for ischaemic heart disease, whereas ischaemic heart disease was the largest contributor to all-cause mortality inequalities in Europe.[2,5] This reflects

Table 3 Cause-specific age-standardized mortality rate by educational level (30–79 years old, per 100 000 person-years) and inequality indices during 2010–15[a]

	High (ISCED 5–8)		Middle (ISCED 3, 4)		Low (ISCED 1, 2)		Inequality indices			
	ASMR	**95% CI**	**ASMR**	**95% CI**	**ASMR**	**95% CI**	**SII**	**95% CI**	**RII**	**95% CI**
Men										
Cause-specific death (ICD-10)										
Certain infectious and parasitic diseases (A00-B99)	19.2	17.5, 21.0	22.6	21.3, 23.9	28.1	26.0, 30.2	9	6, 13	1.57	1.36, 1.83
Neoplasms										
Stomach cancer (C16)	57.0	54.1, 59.9	71.5	69.3, 73.8	75.7	72.5, 78.8	25	19, 31	1.45	1.33, 1.58
Colorectal cancer (C18-C20)	54.5	51.7, 57.2	58.5	56.4, 60.5	60.4	57.6, 63.2	8	2, 13	1.14	1.04, 1.25
Liver cancer (C22)	42.7	40.2, 45.3	51.3	49.4, 53.2	49.5	47.0, 52.0	10	6, 15	1.26	1.14, 1.40
Pancreatic cancer (C25)	40.3	37.9, 42.7	37.5	35.9, 39.1	35.2	33.0, 37.3	N/A		0.82	0.73, 0.91
Lung cancer (C33-34)	98.9	95.0, 102.8	113.7	110.8, 116.6	125.2	121.3, 129.2	35	28, 43	1.38	1.29, 1.47
Leukaemia (C91-C95)	11.1	9.8, 12.3	11.3	10.4, 12.2	12.2	10.9, 13.6	1	−1, 4	1.13	0.92, 1.38
Ischaemic heart diseases (I20-I25)	74.8	71.5, 78.0	85.2	82.7, 87.7	93.8	90.0, 97.6	24	18, 30	1.34	1.24, 1.44
Cerebrovascular diseases (I60-I69)	79.7	76.2, 83.1	96.0	93.3, 98.6	117.0	112.9, 121.0	47	40, 53	1.68	1.56, 1.80
Diabetes (E10-E14)	11.7	10.3, 13.0	16.8	15.7, 17.9	18.5	16.9, 20.1	11	9, 14	2.20	1.84, 2.65
Liver disease (K70-K76)	18.5	17.0, 20.0	25.2	23.9, 26.5	30.4	28.0, 32.9	15	12, 19	1.97	1.70, 2.27
Kidney failure (N17-N19)	13.0	11.6, 14.5	15.9	14.8, 17.0	19.1	17.5, 20.6	N/A		1.63	1.36, 1.95
Suicide (X60-X84, Y87.0)	32.5	30.9, 34.2	42.0	40.4, 43.6	48.0	44.5, 51.5	24	20, 28	1.85	1.66, 2.05
Road traffic accidents (V01-V89, Y85)	7.6	6.7, 8.6	9.0	8.2, 9.7	11.4	9.9, 12.9	5	3, 7	1.83	1.46, 2.31
Women										
Cause-specific death (ICD-10)										
Certain infectious and parasitic diseases (A00-B99)	11.3	9.6, 13.1	12.8	12.0, 13.7	18.9	17.2, 20.5	9	7, 12	2.07	1.69, 2.54
Neoplasms										
Stomach cancer (C16)	21.3	19.1, 23.6	24.3	23.1, 25.4	28.9	26.9, 30.9	10	7, 14	1.50	1.30, 1.73
Colorectal cancer (C18-C20)	46.8	43.4, 50.3	32.0	30.7, 33.3	36.1	33.7, 38.5	N/A		0.72	0.64, 0.81
Liver cancer (C22)	11.1	9.3, 12.8	15.6	14.7, 16.5	18.4	17.1, 19.7	10	7, 13	1.94	1.61, 2.34
Pancreatic cancer (C25)	25.6	23.1, 28.1	27.5	26.3, 28.7	25.3	23.5, 27.1	−4	−8, 0	0.84	0.73, 0.97
Lung cancer (C33-34)	26.6	24.0, 29.3	33.5	32.2, 34.8	39.3	36.9, 41.8	15	10, 19	1.58	1.39, 1.80
Breast cancer (C50)	31.0	28.7, 33.2	30.5	29.3, 31.8	25.8	23.4, 28.3	−7	−11, −3	0.82	0.72, 0.93
Leukaemia (C91-C95)	4.8	3.9, 5.8	6.0	5.4, 6.5	5.9	5.0, 6.9	N/A		1.10	0.82, 1.47
Ischaemic heart diseases (I20-I25)	24.4	21.6, 27.1	34.6	33.2, 36.0	42.6	39.8, 45.4	13	9, 17	1.58	1.39, 1.80
Cerebrovascular diseases (I60-I69)	39.8	36.4, 43.2	56.6	54.9, 58.4	64.9	61.8, 68.0	28	23, 34	1.69	1.53, 1.87
Diabetes (E10-E14)	5.3	4.0, 6.6	5.8	5.3, 6.4	9.4	8.3, 10.5	6	4, 7	2.80	2.07, 3.78
Liver disease (K70-K76)	6.3	5.1, 7.5	11.2	10.4, 11.9	13.8	12.0, 15.6	7	5, 9	2.07	1.64, 2.60
Kidney failure (N17-N19)	5.2	4.0, 6.5	7.8	7.2, 8.5	12.7	11.5, 13.9	9	7, 11	3.53	2.71, 4.60
Suicide (X60-X84, Y87.0)	14.2	12.9, 15.5	16.9	15.9, 17.8	18.0	15.7, 20.3	5	2, 8	1.25	1.05, 1.48
Road traffic accidents (V01-V89, Y85)	2.2	1.6, 2.9	3.3	2.9, 3.7	6.1	5.0, 7.3	N/A		3.91	2.65, 5.78

ASMR, age-standardized mortality rate; CI, confidence interval; ICD-10, the International Classification of Diseases 10th revision; ISCED, International Standard Classification of Education, Slope Index of Inequality (per 100 000 person-years); N/A, convergence not achieved for SII calculation; RII, Relative Index of Inequality; SII, Slope Index of Inequality (per 100 000 person-years).

[a] ASMRs were computed using the 2015 Japan standard population and data in 5-year age intervals.

Table 4 Population attributable fraction (PAF) by educational level, cause-specific contributions to the all-cause PAF and estimated number of excess premature deaths (30–79 years old) in 2010

	Men			Women		
	PAF (%)	**Cause-specific contributions to all-cause PAF (%)**	**Number of excess premature deaths in 2010[a]**	**PAF (%)**	**Cause-specific contributions to all-cause PAF (%)**	**Number of excess premature deaths in 2010[a]**
All-cause	11.6		40 110	16.3		28 552
All cancer (C00-D48)		24.6	9843		19.4	5545
Diseases of the circulatory system (I00-I99)		26.4	10 579		38.9	11 105
External causes (V01-Y98)		11.6	4671		11.5	3286
Others[b]		37.4	15 018		30.2	8616

[a] The total number of deaths in Japan from the official death record in 2010 was 520 946 (30–79 years; 345 778 men and 175 168 women).
[b] All deaths expect for ‘all cancer’, ‘diseases of the circulatory system’ and ‘external causes’.

the high prevalence of cerebrovascular disease in Japan, probably due to the low fat diet but high salt intake.[11] Also, mortality from alcohol-related causes showed small inequalities in absolute terms compared with other causes of death. On the other hand, findings on the main cause-specific contributors (liver disease and transport accidents) to income-based mortality inequalities in South Korea were based on data from public servants and their dependents in the late 1990s to the early 2000s, which likely accounts for the difference with our results.[28]

We found that the magnitude of relative inequality by educational level was similar for the two sexes in Japan. In absolute terms, the magnitude of inequality (SII) was more prominent for men than for women. This is because mortality differences for each cancer site were smaller for women than for men, in addition to the low absolute value of mortality for women. It seems that the relationships between educational level and cancer mortality are weak for Japanese women, which results in small mortality inequalities from all cancer in both absolute and relative terms. A better understanding of health inequality requires that mortality inequalities in cancer be evaluated for each cancer site individually, and not only by the broad grouping of cancers. Moreover, an investigation of socioeconomic inequalities in cancer incidence and survival rate is also required to clarify the overall picture of the cancer burden.[29]

Our findings are broadly consistent with those reported in other high-income countries.[2–5,9] However, our relative inequality estimates (RII: 1.48 for men and 1.47 for women: all-cause mortality) may be smaller in magnitude than in these other reports. For example, RII for men aged 35–79 years ranged from 1.8 in Scotland to 2.2 in France and 3.3 in Lithuania during 2005–09 whereas RII for women ranged from 1.6 in Italy to 2.2 in Finland and 3.6 in Lithuania.[3] Suppose that small mortality inequalities were observed in Japan, this might reflect high standards for general hygiene and living conditions regardless of socioeconomic status,[11] an affordable medical care system and higher levels of social cohesion. Further study is necessary to clarify whether mortality inequalities are actually small and the reasons (e.g. causal effects and modification factors).

Tackling health inequalities requires the establishment of country-tailored strategies, such as 'Health Japan 21'.[14] Unfortunately, Japan is still in the awareness stage of health inequality, even though most other high-income countries have launched nationwide activities to reduce health inequalities. The data presented in this study will aid the development of a national health inequality monitoring framework to guide nationwide plans and actions towards reducing health inequalities in Japan. For example, the ranking of cause-specific contributions to mortality inequalities provides useful information for setting policy priorities.

Limitations

This study has several limitations. First, the national census-linked mortality data have four major limitations, as discussed in the methodology paper: (i) overestimation of mortality due to the generated 'matching key'; (ii) regional sampling bias (underestimated for individuals living in highly populated municipalities); (iii) underestimation of mortality of highly educated individuals; and (iv) possibility of 'matching key' changes.[15] Estimations in the current analysis are consistent with those reported in the methodology paper.[15] Further, regional sampling bias was reduced by increasing the size of the sample population. Nevertheless, an overestimation of mortality remains for both sexes, particularly for the young generations, which resulted in an 11.4% over-ascertainment of deaths for women. The limitations above may result in the overestimation of mortality inequalities in absolute terms, specially for women. Thus, RII should be used as an inequality index for international comparisons, although both absolute and relative terms should be interpreted simultaneously in principle.[3,25]

Second, with regard to data accuracy, we observed that the 'education unknown' rate in the census was 13.0% for men and 11.8% for women (Supplementary Tables S1 and S2, available as Supplementary data at *IJE* online). Given that our dataset was based on the census, these missing data are inevitable. The results of the multiple imputation analysis shown in Supplementary Table S3 (available as Supplementary data at *IJE* online) indicated ASMRs by educational level and inequality indices similar to our main results for both sexes (RII: 1.48 in our main results and 1.49 with multiple imputed data for men; 1.47 in our main results and 1.42 with multiple imputed data for women: all-cause mortality). Therefore, these missing data are unlikely to have distorted our primary findings.

Third, underestimation of mortality of highly educated women aged 75–79 years might have occurred (Supplementary Figure S2B, available as Supplementary data at *IJE* online), which would have resulted in the overestimation of mortality inequalities for women. The multiple imputation analysis also implies the slight underestimation of mortality of highly educated women in our main analysis. If present, however, this effect would not have produced any substantial distortion in our findings: for example, the ASMR ratio between low and high education levels for those aged 30–74 years (age-restricted analysis excluding 75–79 years) was 1.40 (95% CI: 1.27–1.52) for women, which was not divergent from the estimation among those aged 30–79 years. For cause-specific death, female ASMRs from colorectal cancer should be interpreted with caution; the mortality of highly educated women aged 70–79 years appears unstable, probably due to random error. In any case however, we confirmed that highly educated women aged 30–69 years had a relatively higher ASMR from colorectal cancer than those with low education.

Finally, for international comparisons, classification of educational level should be considered carefully. In Japan, the high school enrolment rate is quite high, and only 14.5% of men and 15.2% of women Japanese aged 30–79 years in 2010 had not completed upper secondary or post-secondary non-tertiary education. In addition, the university enrolment rate is increasing along with the declining birth rate. The category of 'high education' in Japan may represent a more heterogeneous group than in Western countries, where university entrance examination selection is hard.

Conclusion

For the Japanese population, which is considered excellent for health, clear educational inequalities in mortality and higher mortality risk among lower educational levels are evident for most kinds of cause-specific death, particularly cerebrovascular diseases, ischaemic heart diseases and lung cancer in the early 2010s. Various causal pathways of health inequality still require attention; in particular, reducing diseases of the circulatory system and smoking-related diseases is a key target to reducing mortality inequality.

Ethics approval

Ethics approval was not applicable. This study is a secondary use of census and vital statistics data which were anonymized by the Ministry of Internal Affairs and Communications and the Ministry of Health, Labour and Welfare. The Ministry of Internal Affairs and Communications and the Ministry of Health, Labor, and Welfare provided data after considering data management and protection compliance.

Data availability

The data underlying this article will be shared on reasonable request to the corresponding author, but individual data are not available from the authors due to data protection.

Supplementary data

Supplementary data are available at *IJE* online.

Author contributions

H.T. had full access to all the study data. All authors had access to census-linked mortality data. H.T. was responsible for the integrity of the data, the accuracy of the data analysis and the drafting of the manuscript. All authors contributed to data analysis and the concept and design of the study. All authors critically reviewed the manuscript. Y.K. and K.K. supervised the study and provided administrative, technical and material support.

Funding

This work was supported by the Japan Society for the Promotion of Science (JSPS) KAKENHI (grant number: 21K21188; 23K16341).

Acknowledgements

Not applicable.

Conflict of interest

None declared.

References

1. Hosseinpoor AR, Bergen N, Schlotheuber A, Grove J. Measuring health inequalities in the context of sustainable development goals. *Bull World Health Organ* 2018;**96**:654–59.
2. Mackenbach JP, Stirbu I, Roskam AJ *et al.*; European Union Working Group on Socioeconomic Inequalities in Health. Socioeconomic inequalities in health in 22 European countries. *N Engl J Med* 2008;**358**:2468–81.
3. Mackenbach JP, Kulhanova I, Artnik B *et al.* Changes in mortality inequalities over two decades: register based study of European countries. *BMJ* 2016;**353**:i1732.
4. Alicandro G, Frova L, Sebastiani G, Boffetta P, La Vecchia C. Differences in education and premature mortality: a record linkage study of over 35 million Italians. *Eur J Public Health* 2018;**28**:231–37.
5. Renard F, Gadeyne S, Devleesschauwer B, Tafforeau J, Deboosere P. Trends in educational inequalities in premature mortality in Belgium between the 1990s and the 2000s: the contribution of specific causes of deaths. *J Epidemiol Community Health* 2017;**71**:371–80.
6. van Hedel K, Avendano M, Berkman LF *et al.* The contribution of national disparities to international differences in mortality between the United States and 7 European countries. *Am J Public Health* 2015;**105**:e112–19.
7. Tjepkema M, Wilkins R, Long A. Socio-economic inequalities in cause-specific mortality: a 16-year follow-up study. *Can J Public Health* 2013;**104**:e472–78.
8. Korda RJ, Biddle N, Lynch J *et al.* Education inequalities in adult all-cause mortality: first national data for Australia using linked census and mortality data. *Int J Epidemiol* 2020;**49**:511–18.
9. Welsh J, Joshy G, Moran L *et al.* Education-related inequalities in cause-specific mortality: first estimates for Australia using individual-level linked census and mortality data. *Int J Epidemiol* 2022;**50**:1981–94.
10. Blakely T, Tobias M, Atkinson J. Inequalities in mortality during and after restructuring of the New Zealand economy: repeated cohort studies. *BMJ* 2008;**336**:371–75.
11. Ikeda N, Saito E, Kondo N *et al.* What has made the population of Japan healthy? *Lancet* 2011;**378**:1094–105.
12. Kagamimori S, Gaina A, Nasermoaddeli A. Socioeconomic status and health in the Japanese population. *Soc Sci Med* 2009;**68**:2152–60.
13. Ikegami N, Yoo BK, Hashimoto H *et al.* Japanese universal health coverage: evolution, achievements, and challenges. *Lancet* 2011;**378**:1106–15.
14. Tsuji I. Current status and issues concerning Health Japan 21 (second term). *Nutr Rev* 2020;**78**:14–17.
15. Tanaka H, Mackenbach JP, Kobayashi Y. Estimation of socioeconomic inequalities in mortality in Japan using national census-linked longitudinal mortality data. *J Epidemiol* 2023;**33**:246–55.
16. Tanaka H, Mackenbach JP, Kobayashi Y. Widening Socioeconomic Inequalities in Smoking in Japan, 2001-2016. *J Epidemiol* 2021;**31**:369–77.
17. Tanaka H, Mackenbach JP, Kobayashi Y. Trends and socioeconomic inequalities in self-rated health in Japan, 1986-2016. *BMC Public Health* 2021;**21**:1811.
18. Tanaka H, Nusselder WJ, Kobayashi Y, Mackenbach JP. Socioeconomic inequalities in self-rated health in Japan, 32 European countries and the United States: an international comparative study. *Scand J Public Health* 2023;**51**:1161–72.
19. Tanaka H, Nusselder WJ, Bopp M *et al.* Mortality inequalities by occupational class among men in Japan, South Korea and eight European countries: a national register-based study, 1990-2015. *J Epidemiol Community Health* 2019;**73**:750–58.
20. Tanaka H, Toyokawa S, Tamiya N, Takahashi H, Noguchi H, Kobayashi Y. Changes in mortality inequalities across occupations in Japan: a national register based study of absolute and relative measures, 1980-2010. *BMJ Open* 2017;**7**:e015764.
21. Ministry of Internal Affairs and Communications. *Population Census*. 2017. https://www.stat.go.jp/data/kokusei/2015/ (2 June 2023, date last accessed).
22. Ministry of Health, Labour and Welfare. *Vital Statistics*. Ministry of Health Labour and Welfare. 2018. https://www.mhlw.go.jp/english/database/db-hw/vs01.html (2 June 2023, date last accessed).
23. Tanaka H, Tanaka S, Togawa K, Katanoda K. Practical implications of the update to the 2015 Japan Standard Population: mortality archive from 1950 to 2020 in Japan. *J Epidemiol* 2023;**33**:372–80.
24. United Nations Educational, Scientific and Cultural Organization. *International Standard Classification of Education ISCED 2011*. United Nations Educational, Scientific and Cultural Organization, 2018. http://uis.unesco.org/sites/default/files/documents/international-standard-classification-of-education-isced-2011-en.pdf (2 June 2023, date last accessed)
25. Mackenbach JP, Kunst AE. Measuring the magnitude of socioeconomic inequalities in health: an overview of available measures illustrated with two examples from Europe. *Soc Sci Med* 1997;**44**:757–71.
26. Mansournia MA, Altman DG. Population attributable fraction. *BMJ* 2018;**360**:k757.

27. Iwasaki M, Otani T, Inoue M, Sasazuki S, Tsugane S; Japan Public Health Center-based Prospective Study Group. Role and impact of menstrual and reproductive factors on breast cancer risk in Japan. *Eur J Cancer Prev* 2007;**16**:116–23.
28. Jung-Choi K, Khang YH, Cho HJ. Socioeconomic differentials in cause-specific mortality among 1.4 million South Korean public servants and their dependents. *J Epidemiol Community Health* 2011;**65**:632–38.
29. Odani S, Tabuchi T, Nakaya T *et al.* Socioeconomic disparities in cancer survival: Relation to stage at diagnosis, treatment, and centralization of patients to accredited hospitals, 2005-2014, Japan. *Cancer Med* 2023;**12**:6077–91.