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ORIGINAL ARTICLE

Quantifying the impact of reducing socioeconomic inequalities in modifiable risk factors on mortality and mortality inequalities in South Korea

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Abstract

Objectives We quantified the impact of reducing socioeconomic inequalities in risk factors on mortality and mortality inequalities in South Korea.

Methods The mortality risk function from the 12-year mortality follow-up data of the National Health Insurance Service-National Health Screening Cohort, the prevalence of major risk factors from the Korea National Health and Nutrition Examination Survey 2013–2015, and the Health Plan 2020 (HP2020) goals for major risk factors were used to estimate the magnitude of reduction in mortality inequalities by changing the magnitude of income-based inequalities in risk factors in various scenarios under gender-specific models among participants aged 40–79 years.

Results The greatest reduction in absolute and relative inequalities in mortality would occur if the low-income group achieved the HP2020 goals earlier than the high-income group. A 10–20% reduction in all-cause mortality inequalities was expected if absolute gaps between income groups in risk factors were halved.

Conclusions With the practical goal halving the socioeconomic gaps in modifiable risk factors, reducing inequalities in all-cause mortality by 10–20% would be possible. Further reduction in mortality inequalities would need more aggressive policies on social determinants of health.

Keywords Mortality · Socioeconomic status · Risk factors · Inequalities · Health plan

Introduction

Health inequalities are an important public health problem globally, as well as in South Korea (CSDH 2008; Mackenbach et al. 2008; Stringhini et al. 2010; Khang and Lee 2012; Di Cesare et al. 2013). Inequalities in health outcomes are created by unequal distributions of modifiable risk factors according to socioeconomic groups, such as smoking, hypertension, and obesity (Lynch et al. 2006; Kivimaki et al. 2008; Khang et al. 2008, 2009; Östergren et al. 2018). Previous studies have shown that the magnitude of absolute health inequalities can be greatly reduced if modifiable risk factors are completely removed from the population (Lynch et al. 2006; Kivimaki et al. 2008; Khang et al. 2008, 2009). However, although theoretically interesting, completely eliminating risk factors from the population is not a realistic policy option.

Many countries have established 10–50% reductions in inequalities in health outcomes such as mortality or life expectancy as quantifiable health equity goals (Health 21 1999; MOHW 2005; Crombie et al. 2005; Department of Health 2009; Haber and Wong 2013). To achieve equity in health outcomes, several countries also have set the goal of reducing the socioeconomic gap in risk factors such as smoking (MOHW 2005; Crombie et al. 2005; Haber and Wong 2013). However, it is uncertain whether strategies to reduce socioeconomic gaps in modifiable risk factors

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would result in a meaningful reduction in inequalities in health outcomes.

In South Korea, health inequalities according to income have been reported (Khang and Kim 2005; Khang et al. 2008; Jung-Choi and Khang 2011; Jung-Choi et al. 2011). The Health Plan 2020 (HP2020) aims to reduce the gap between income quartiles in smoking to 8% in men and 1.5% in women (HP2020 Report 2011). The HP2020 also provides the following health indicators of risk factors as national goals to achieve by 2020 for improving the health of all Koreans: reduction in the prevalence of hypertension to 23%, high cholesterol to 13.5%, diabetes to 11%, current smoking to 29% in men and 6% in women, and overweight (25 kg/m^2 or over) to 37% in men and 27% in women. These health indicators of risk factors are defined in a way that applies equally to all social groups. However, the prevalence of major risk factors remains the highest in the most disadvantaged socioeconomic groups, leading to inequalities in health outcomes (Khang et al. 2008, 2009; Kim et al. 2017).

Simulation studies may provide useful evidence on reducing socioeconomic inequalities in health (Speybroeck et al. 2013; Smith et al. 2014). Several prior studies have explored how the magnitude of inequalities in health outcomes would change when the socioeconomic gap in risk factors is reduced in various scenarios (Alvarado et al. 2009; Hoffmann et al. 2013, 2015; Scholes et al. 2013; Kulik et al. 2013; Mäki et al. 2014; Eikemo et al. 2014; Kulhánová et al. 2016). In particular, the EURO-GBD-SE project has quantified the impact of changing the socioeconomic distribution of risk factors on socioeconomic inequalities in health outcomes in European countries (Hoffmann et al. 2013, 2015; Kulik et al. 2013; Mäki et al. 2014; Eikemo et al. 2014; Kulhánová et al. 2016). However, to the best of our knowledge, no investigations on the impact of simulated changes in the socioeconomic distribution of risk factors on inequalities in health outcomes have been reported from Asian countries.

This study explored how inequalities in mortality from all causes, cardiovascular disease (CVD), and cancer would be affected by changing the magnitude of inequalities in risk factors by income, using data from the Korea National Health and Nutrition Examination Survey (KNHANES) (Kweon et al. 2014) and the National Health Insurance Service-National Health Screening Cohort (NHIS-HEALS) (Seong et al. 2017). All analysis results were presented separately by gender.

Methods

Scenarios

We considered seven scenarios in which the magnitude of inequalities in risk factors according to income was changed. Each scenario represented a different preventive strategy. In each scenario, the magnitudes of reduction in both mortality in the whole population and inequalities in mortality from all causes, CVD, and cancer were estimated. The details of the seven scenarios are shown in Table 1. Figure 1 provides an example of the scenarios for current smoking in men.

Data sources and data usage

Data from the NHIS-HEALS (the 2002–2003 baseline and the follow-up until 2013) were used to obtain a risk function (Cox regression model) explaining the associations between risk factors and the 12-year absolute risk of all-cause, CVD, and cancer mortality. Data from the KNHANES 2013–2015 were used to determine the current distribution of risk factors, because the NHIS-HEALS at the 2002–2003 baseline would overestimate or underestimate the current prevalence of some risk factors; for example, the prevalence of diabetes has increased, while the prevalence of current smoking has decreased since 2002–2003.

The risk function obtained from the NHIS-HEALS was applied to the current distribution of risk factors observed from the KNHANES 2013–2015 to predict the absolute 12-year risk of mortality from all causes, CVD, and cancer under the current distribution of risk factors. The mortality risk in 2013–2015 was obtained for each income group by including income in the risk function. The risk function from the NHIS-HEALS was also applied to the distribution of risk factors simulated under each scenario. We evaluated the expected risks under various scenarios against the current predicted risk to set targets for reducing health inequalities for all-cause, CVD, and cancer mortality.

The NHIS-HEALS is a cohort of participants who participated in national health screening programs provided by the NHIS in South Korea. Details of this cohort were reported previously (Seong et al. 2017). A sample cohort was first selected from the 2002 and 2003 health screening participants, who were aged between 40 and 79 in 2002 and followed up through 2013. This cohort included information on 514,866 health screening participants, who comprised a 10% random sample of all health screening participants in 2002 and 2003. For NHIS-HEALS, information on gender, age, income, and the major risk factors for participants at baseline 2002–2003 and the cause of

Table 1 A detailed description of seven scenarios, South Korea, 2018

Scenario 1: the risk factor levels in all income groups achieve the Health Plan 2020 (HP2020) goals, i.e., it is an ideal case
Scenario 2: the risk factor levels of all income groups achieve the risk factor levels of the high-income group in the current distribution of risk factors
Scenario 3: the risk factor levels of the high-income group remain the same, while the absolute gaps between income groups in risk factors are halved. The relative gaps between income groups in risk factors are also reduced
Scenario 4: the risk factor levels at the population level (mean values of risk factors) achieve the HP2020 goals, and the risk factor levels for each income group are proportionally reduced. Thus, the relative gaps between income groups in risk factors remain the same, while the absolute gaps between income groups in risk factors are reduced
Scenario 5: the risk factor levels at the population level (mean values of risk factors) achieve the HP2020 goals, and the absolute gaps in risk factors between each income group and the overall population mean in Scenario 4 are reduced by half. The relative gaps between income groups in risk factors are reduced compared to the current distribution of risk factors
Scenario 6: the risk factor levels of the low-income and median-income groups achieve the HP2020 goals
Scenario 7: the risk factor levels of the low-income group achieve the HP2020 goals, and the risk factor levels of the middle-income and high-income groups achieve half of the absolute gaps from the HP2020 goals

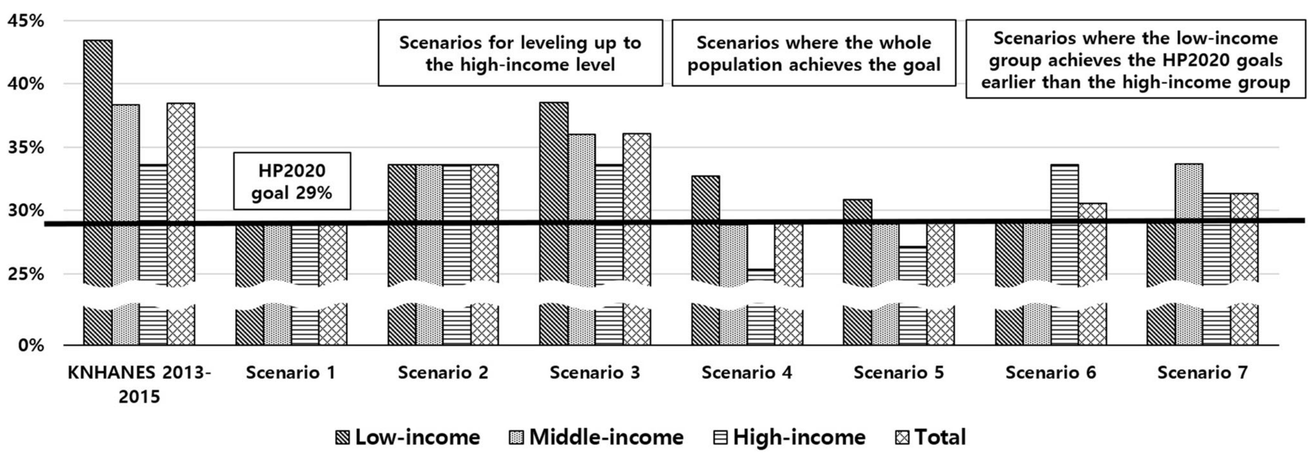

Fig. 1 Expected prevention scenarios. The figure shows an example of changes in current smoking in men according to the seven scenarios. The absolute gaps between income groups are observed in the Korea National Health and Nutrition Examination Survey (KNHANES) 2013–2015 data, as shown in the left-most set of values. The Health Plan 2020 (HP2020) goal for current smoking prevalence in men is 29%, South Korea, 2018

death and the date of death of people who died during the follow-up period until 2013 were used to obtain the Cox regression model. We focused on three broad causes of death: all causes, CVD, and cancer. For the primary and secondary causes of death in the death certificate, CVD and cancer deaths were identified using ICD-10 codes as follows: CVD [ischemic heart diseases (I20–I25) and cerebrovascular diseases (I60–I69)], and cancer (C00–C97). CVD or cancer patients identified at the 2002–2003 baseline were excluded from the analysis.

The KNHANES is a nationwide cross-sectional survey conducted annually to assess the health and nutritional status of Koreans (Kweon et al. 2014). We used data from the sixth KNHANES (2013–2015), which is a nationally representative sample of Korean adults. Information from the KNHANES on gender, age, income, and major risk factors for participants was used for the analysis.

In both NHIS-HEALS and KNHANES, data from participants aged 40–79 years with complete information on risk factors were used in the analysis. As a result, the NHIS-HEALS included 267,885 men and 226,516 women (see Online Resource, Supplementary Table 1), and the KNHANES included 4063 men and 5397 women.

Socioeconomic position

In this study, annual household income was used as an indicator of socioeconomic position, since the HP2020 set health equity goals according to income (HP2020 Report 2011). In the KNHANES, income groups were created by dividing equivalized household income (i.e., annual household income ÷ (household size)$^{0.5}$) from household surveys into three groups (low-income, median-income, high-income) according to gender and 5-year age group. In the NHIS-HEALS, income groups were created by dividing income-based insurance contributions in 2002 (a proxy for household income) into three groups according to gender and 5-year age group. Prior Korean studies on socioeconomic inequalities in mortality employed this income-based insurance contributions as a measure for income (Khang et al. 2008; Jung-Choi and Khang 2011; Jung-Choi et al. 2011).

Risk factors and associated HP2020 goals

We considered five major risk factors associated with mortality from all causes, CVD, and cancer: hypertension, hypercholesterolemia, diabetes, current smoking, and obesity (Khang et al. 2008, 2009; Kivimaki et al. 2008; Alvarado et al. 2009; Kulik et al. 2013; Eikemo et al. 2014; Hoffmann et al. 2013, 2015). The risk factors at baseline in NHIS-HEALS and KNHANES were classified according to the following criteria: (1) Blood pressure was classified according to systolic blood pressure (SBP, mm Hg) and diastolic blood pressure (DBP, mm Hg): SBP $<$ 120 and DBP $<$ 80 (normal), 120 $\leq$ SBP $<$ 140 or 80 $\leq$ DBP $<$ 90 (pre-hypertension), or SBP $\geq$ 140 or DBP $\geq$ 90 (hypertension). The hypertension group also included people who were prescribed hypertension medication at baseline; (2) Total cholesterol (mg/dL) was classified as $<$ 200 (desirable), 200–239 (borderline high), or $\geq$ 240 (high). The high-cholesterol group also included people who were prescribed hypercholesterolemia medication at baseline; (3) Fasting blood sugar (mg/dL) was classified as $<$ 100 (normal), 100–125 (prediabetes), or $\geq$ 126 (diabetes). The diabetes group also included people who were prescribed diabetes medication at baseline; (4) Current smoking status was obtained from answers to the questions about cigarette smoking status at baseline; (5) Body mass index (BMI, kg/m^2) was calculated as body weight divided by height squared and then classified into three groups: $<$ 18.5 (underweight), 18.5–24.9 (normal), $\geq$ 25 (overweight or obesity).

In this study, some of the HP2020 goals for risk factors have changed. That is, the goals of 35% instead of 37% in men for obesity, 25% instead of 27% in women for obesity, and 1% instead of 6% in women for current smoking were used. This is because the prevalence of some risk factors in the KNHANES 2013–2015 data had already achieved the HP2020 goal. In addition, the rates of 0.8% in men and 1.8% in women were used as a health indicator for the prevalence of underweight, because underweight was considered to have an impact on mortality in this study.

Statistical analysis

The details of our analysis procedures are presented in Online Resource, Supplementary material.

Step 1 (*Datasets*) We created the NHIS-HEALS and KNHANES datasets with complete information on gender, age, income, risk factors, and the cause of death and survival time (for NHIS-HEALS). The datasets included participants aged 40–79 years who were not CVD or cancer patients at baseline.

Step 2 (*Cox regression model for the NHIS-HEALS data*) We constructed a gender-specific Cox regression model for survival time (for each event of all-cause, CVD, and cancer mortality) with age, income, and the five risk factors as predictor variables in the NHIS-HEALS data, and then we obtained β coefficients. The Cox regression results are presented in Online Resource, Supplementary Table 2. The predictive accuracy of the Cox regression model was evaluated by the C-statistic. The C-statistics of the models for all-cause, CVD, and cancer mortality were 0.81, 0.85, and 0.79 for men and 0.84, 0.88, and 0.75 for women, respectively, showing that the prediction models had excellent (C-statistic: 0.8–0.9) or acceptable (C-statistic: 0.7–0.8) abilities to distinguish between those who experienced the event of interest and those who did not (Hosmer and Lemeshow 2000). We evaluated the calibration of the models with a calibration plot that showed how closely the predicted outcomes agreed with the actual outcomes. The graphical results of the calibration are presented in Online Resource, Supplementary Figure 1, and showed good agreement between the observed and predicted mortality rates.

Step 3 (*12-year mortality risk under the current [KNHANES] distribution of risk factors*) We calculated the predicted 12-year mortality risk (for all-cause, CVD, and cancer mortality) for each income group in KNHANES 2013–2015 using the recalibration method (D'Agostino et al. 2001; Alvarado et al. 2009) (see Online Resource, Supplementary material for further details). Note that the income in Step 2 was entered into the risk function only as a main effect, so the β coefficients for the risk factors were assumed to be the same across all income groups.

Step 4 (*12-year mortality risk under hypothetical scenarios*) As with the method in Step 3, we obtained the predicted 12-year mortality risk (for all-cause, CVD, and cancer mortality) for each income group by gender under seven hypothetical scenarios, by changing the current distribution of risk factors in KNHANES 2013–2015 to the distribution of risk factors corresponding to each hypothetical scenario. The distributions of risk factors for the seven hypothetical scenarios by gender are presented in Online Resource, Supplementary Tables 3–6.

Step 5 (*Mortality risk reduction*) First, we examined the impact of income inequalities of risk factors on mortality at the whole-population level. The overall risk reduction in all-cause, CVD, and cancer mortality was obtained by comparing the overall mortality risk (P_C) obtained under the current distribution of risk factors in the KNHANES 2013–2015 with the overall mortality risk (P_S) obtained under each hypothetical scenario: $(P_C - P_S)/P_C \times 100$. Second, we examined the impact of income inequalities of risk factors on mortality by comparing the predicted mortality risks obtained from Step 3 and Step 4 using the following indicators: relative risk (RR), absolute risk (AR), relative index of inequality (RII), and slope index of inequality (SII). The RR and AR involve pairwise comparisons of different groups and were used for income groups (the low-income and median-income groups, compared to the high-income group). The RII and SII are summary measures of the relative and absolute inequality, respectively, recommended when making comparisons across the population ordered by income level rather than comparing the two extremes of the social hierarchy (Mackenbach and Kunst 1997; Harper and Lynch 2006).

Results

Baseline characteristics and relative risk comparisons in the NHIS-HEALS

The baseline characteristics and gender-specific age-adjusted RRs of mortality are presented in Online Resource, Supplementary Tables 1 and 10, and the associated findings are presented in detail in Online Resource, Supplementary material.

Scenarios of risk factor changes, associated mortality risks, and inequalities by income

In the prevalence of risk factors in the KNHANES 2013–2015, the high-income group was closer to achieving the HP2020 goals for risk factors than the low-income group (see Online Resource, Supplementary Table 11).

Table 2 shows the overall risks for mortality from all causes, CVD, and cancer at the whole-population level for men and women in the KNHANES 2013–2015. Under the current distribution of risk factors, the overall risks for all-cause, CVD, and cancer mortality were 8.87, 1.29, and 3.80% in men and 5.02, 0.97, and 1.68% in women, respectively. The greatest relative reduction in overall mortality risk was found in Scenario 1, where the risk factor levels in all income groups meet the HP2020 goals, and in Scenario 4 and Scenario 5, where the risk factor levels at the population level achieve the HP2020 goals, but the absolute and relative gaps between income groups in risk factors remain: 8.9% in men and 4.8% in women for all-cause mortality, 20.5% in men and 11.8% in women for CVD mortality, and 5.4% in men for cancer mortality, with the exception of cancer mortality in women. In contrast, in Scenario 2 and Scenario 3, where all income groups achieve the risk factor levels of the high-income group, the reduction in the overall mortality risk was much lower, with the exception of cancer mortality in women. The greatest reduction was observed in CVD mortality, and the reduction in overall mortality risk in men was greater than in women.

Table 3 shows the results for RIIs and SIIs. The greatest reduction in RIIs (SIIs) was found in Scenario 6, where low-income and median-income groups achieve the HP2020 goals, with the exception of cancer mortality in women: 37.1% (33.1%) in men and 39.2% (37.0%) in women for all-cause mortality, 70.3% (67.5%) in men and 52.5% (49.3%) in women for CVD mortality, and 32.0% (29.3%) in men for cancer mortality. The results for RRs and ARs and their explanations are found in Online Resource, Supplementary material.

Figure 2 is a graphical representation of the results from Tables 2 and 3, showing the relationship between the reduction in overall population mortality risk and the reduction in inequalities in mortality across the income groups. As mentioned earlier, Scenarios 1, 4, and 5, which reduce the risk factor levels across the whole population, produced greater reductions in the overall population mortality risk than Scenarios 2 and 3, which focus on achieving the risk factor levels of the high-income group in all income groups for all-cause, CVD, and cancer mortality, and Scenarios 6 and 7, where low-income group achieves the HP2020 goals earlier than the high-income group. The reduction in the overall mortality risk in men was greater than in women. The greatest reduction in the RIIs and SIIs was observed in Scenario 6, although these results were not found for cancer mortality in women. The greatest reduction in the overall mortality risk and RIIs and SIIs was observed in CVD mortality.

Discussion

This study presents simulation analyses of the impact of changes in the social distribution of risk factors across income groups on mortality and mortality inequalities. These analyses showed that the greatest reduction in the overall mortality risk (by approximately 9%) would be

Table 2 Seven scenarios in changes in risk factors by income and associated overall mortality risk from all causes, cardiovascular disease (CVD), and cancer in the whole population, South Korea, 2018

	Men		Women	
	12-year risk, % (CI)	Reduction (%)	12-year risk, % (CI)	Reduction (%)
All-cause mortality				
Current risk factors	8.87 (8.76–9.00)	8.9	5.02 (4.93–5.10)	4.8
Scenario 1	8.08 (7.96–8.20)	3.3	4.78 (4.69–4.87)	2.0
Scenario 2	8.58 (8.47–8.70)	1.7	4.92 (4.83–5.00)	1.0
Scenario 3	8.72 (8.62–8.85)	9.0	4.97 (4.88–5.05)	4.8
Scenario 4	8.08 (7.96–8.20)	8.9	4.78 (4.69–4.87)	4.8
Scenario 5	8.08 (7.96–8.20)	7.1	4.78 (4.69–4.87)	3.9
Scenario 6	8.24 (8.12–8.36)	6.7	4.83 (4.73–4.91)	3.8
Scenario 7	8.27 (8.16–8.39)		4.83 (4.74–4.91)	
CVD mortality				
Current risk factors	1.29 (1.25–1.33)	20.5	0.97 (0.92–1.00)	11.8
Scenario 1	1.02 (0.98–1.07)	3.7	0.86 (0.81–0.89)	3.5
Scenario 2	1.24 (1.20–1.28)	1.9	0.94 (0.89–0.97)	1.8
Scenario 3	1.26 (1.22–1.31)	20.5	0.95 (0.91–0.99)	11.8
Scenario 4	1.02 (0.98–1.07)	20.5	0.86 (0.81–0.89)	11.8
Scenario 5	1.02 (0.98–1.07)	15.3	0.86 (0.81–0.89)	9.1
Scenario 6	1.09 (1.04–1.13)	15.0	0.88 (0.84–0.91)	8.8
Scenario 7	1.09 (1.05–1.14)		0.89 (0.84–0.92)	
Cancer mortality				
Current risk factors	3.80 (3.74–3.87)	5.4	1.68 (1.63–1.73)	1.2
Scenario 1	3.60 (3.52–3.68)	3.5	1.66 (1.61–1.72)	1.9
Scenario 2	3.67 (3.61–3.74)	1.8	1.65 (1.60–1.70)	1.0
Scenario 3	3.74 (3.68–3.81)	5.4	1.66 (1.62–1.72)	1.2
Scenario 4	3.60 (3.52–3.68)	5.4	1.66 (1.61–1.72)	1.2
Scenario 5	3.60 (3.52–3.68)	4.8	1.66 (1.61–1.72)	1.5
Scenario 6	3.62 (3.56–3.69)	4.3	1.66 (1.61–1.71)	1.4
Scenario 7	3.64 (3.57–3.71)		1.66 (1.61–1.71)	

The CI for 12-year mortality risk represents the 95% bootstrap confidence interval estimated by the 2.5% and 97.5% percentiles of the distribution of the mortality risks calculated after applying the Cox regression model to the 200 bootstrap samples from the National Health Insurance Service-National Health Screening Cohort (NHIS-HEALS) 2002–2013. The reduction % in 12-year overall mortality risk was calculated by $(P_C - P_S)/P_C \times 100$, where P_C is the predicted risk in the whole population based on the current distribution of risk factors in the Korea National Health and Nutrition Examination Survey (KNHANES) 2013–2015, and P_S is the predicted risk in the whole population based on each of the scenarios

achieved if all income groups achieved the HP2020 goals (Scenario 1) or if the overall population mean achieved the HP2020 goals (Scenarios 4 and 5). The greatest reduction in both absolute and relative inequalities in all-cause mortality (by about 33–39%) was predicted if the low-income and median-income groups achieved the HP2020 goals (Scenario 6) earlier than high-income group. However, Scenario 6, which showed the best results for inequality reduction, would not be practically achievable, since the negative-to-positive reversal of the socioeconomic distribution of risk factors (e.g., cigarette smoking) has not been observed in any industrialized countries. Scenarios 3 and 5, where socioeconomic gaps in risk factors are halved, may represent a practical goal, and these scenarios predicted a reduction in inequalities in all-cause mortality by about 10–20%.

Many countries, including South Korea, have set quantifiable goals or targets ranging from 10 to 50% for reducing inequalities in health (Health 21 1999; MOHW 2005; Crombie et al. 2005; Department of Health 2009; Haber and Wong 2013). The European WHO region has the goal of a 25% reduction in life expectancy inequalities by 2020 (Health 21 1999). The UK government has set targets for a 10% reduction in inequality mortality and life expectancy (Department of Health 2009). The national health plan 2020 of South Korea aimed at reducing relative inequalities in all-cause mortality by 25% (MOHW 2011). The Seoul Metropolitan Government in South Korea also

Table 3 Effect of adjustment of risk factors under different scenarios on relative index of inequality (RII) and slope index of inequality (SII) by income, South Korea, 2018

	Men				Women			
	Relative inequality measure		Absolute inequality measure		Relative inequality measure		Absolute inequality measure	
	RII (CI)	RIIR (%)	SII per 100 000 (CI)	SIIR (%)	RII (CI)	RIIR (%)	SII per 100 000 (CI)	SIIR (%)
All-cause mortality								
Current risk factors	2.13 (2.03–2.25)		6533 (6128–6933)		1.47 (1.38–1.58)		1924 (1616–2264)	
Scenario 1	1.88 (1.79–1.98)	22.6	4986 (4594–5392)	23.7	1.34 (1.26–1.43)	27.4	1401 (1106–1699)	27.2
Scenario 2	1.87 (1.79–1.97)	22.9	5280 (4866–5686)	19.2	1.34 (1.26–1.43)	27.4	1441 (1139–1751)	25.1
Scenario 3	2.00 (1.91–2.11)	11.9	5895 (5486–6288)	9.8	1.40 (1.32–1.51)	14.1	1679 (1358–2017)	12.7
Scenario 4	2.05 (1.96–2.17)	7.1	5664 (5282–6036)	13.3	1.40 (1.32–1.50)	14.7	1606 (1301–1925)	16.5
Scenario 5	1.96 (1.87–2.07)	15.1	5324 (4935–5713)	18.5	1.37 (1.29–1.47)	21.1	1503 (1192–1811)	21.9
Scenario 6	1.71 (1.62–1.81)	37.1	4370 (3914–4792)	33.1	1.29 (1.20–1.38)	39.2	1212 (887–1531)	37.0
Scenario 7	1.78 (1.70–1.87)	31.3	4683 (4282–5111)	28.3	1.31 (1.23–1.40)	33.7	1307 (997–1603)	32.1
CVD mortality								
Current risk factors	2.01 (1.72–2.33)		877 (692–1041)		1.84 (1.57–2.17)		584 (430–732)	
Scenario 1	1.73 (1.49–1.99)	27.9	551 (401–696)	37.2	1.60 (1.36–1.87)	29.4	397 (260–525)	32.1
Scenario 2	1.73 (1.49–1.98)	28.0	667 (490–833)	23.9	1.60 (1.36–1.87)	29.5	434 (287–571)	25.8
Scenario 3	1.86 (1.59–2.15)	14.7	770 (582–933)	12.2	1.71 (1.46–2.00)	15.4	507 (357–651)	13.2
Scenario 4	1.91 (1.63–2.20)	10.1	647 (496–792)	26.2	1.73 (1.48–2.01)	14.1	461 (323–586)	21.1
Scenario 5	1.81 (1.55–2.09)	19.3	599 (452–744)	31.7	1.66 (1.42–1.94)	21.9	429 (292–556)	26.6
Scenario 6	1.30 (1.12–1.49)	70.3	285 (121–442)	67.5	1.40 (1.19–1.64)	52.5	296 (144–436)	49.3
Scenario 7	1.48 (1.28–1.69)	52.7	424 (271–580)	51.6	1.48 (1.27–1.73)	42.6	348 (204–479)	40.5
Cancer mortality								
Current risk factors	1.77 (1.65–1.90)		2136 (1873–2406)		1.26 (1.11–1.43)		393 (174–592)	
Scenario 1	1.57 (1.47–1.68)	26.0	1605 (1372–1840)	24.9	1.17 (1.02–1.32)	36.0	259 (41–459)	34.1
Scenario 2	1.57 (1.47–1.68)	26.1	1637 (1398–1887)	23.4	1.17 (1.02–1.32)	36.0	257 (41–456)	34.6
Scenario 3	1.66 (1.56–1.78)	13.5	1882 (1645–2139)	11.9	1.22 (1.07–1.38)	18.4	324 (106–528)	17.5
Scenario 4	1.71 (1.60–1.84)	7.5	1907 (1659–2156)	10.7	1.21 (1.07–1.38)	19.5	320 (106–525)	18.7
Scenario 5	1.64 (1.54–1.75)	17.0	1756 (1522–1997)	17.8	1.19 (1.04–1.35)	27.8	289 (74–498)	26.4
Scenario 6	1.52 (1.42–1.64)	32.0	1510 (1254–1783)	29.3	1.18 (1.04–1.33)	31.4	276 (64–478)	29.9
Scenario 7	1.54 (1.44–1.65)	29.8	1558 (1317–1809)	27.1	1.18 (1.03–1.32)	33.7	267 (57–468)	32.0

The slope index of inequality (SII) is the difference in the predicted mortality risks at the top (range = 1) and bottom (range = 0) of the income distribution. The relative index of inequality (RII) is the ratio of the predicted mortality risks at the top (range = 1) and bottom (range = 0) of the income distribution; The CI for SII and RII represents the 95% bootstrap confidence intervals estimated by the 2.5% and 97.5% percentiles of the distribution of the SIIs and RIIs for the 12-year mortality risks calculated after applying the Cox regression model to the 200 bootstrap samples from the National Health Insurance Service-National Health Screening Cohort (NHIS-HEALS) 2002–2013. RIIR (RII reduction %) = $[RII_C - RII_S]/[RII_C - 1] \times 100$, SIIR (SII reduction, %) = $[SII_C - SII_S]/SII_C \times 100$, where the subscript ‘C’ represents the current distribution of risk factors in the Korea National Health and Nutrition Examination Survey (KNHANES) 2013–2015, and subscript ‘S’ represents each of the scenarios

set a target for reducing relative mortality inequality by 10% (Seoul Metropolitan Government 2013). The results of the current analysis imply that these health equity targets of 10–20% reductions could be achievable if inequalities in major risk factors are substantially reduced by half. However, the results also indicate that more aggressive policies on fundamental causes (e.g., labor market policies and income redistribution policies) should be developed to reduce inequalities in mortality further (Phelan et al. 2010; Eikemo et al. 2014; McAuley et al. 2016). Prior Korean studies showed that socioeconomic inequalities in mortality and life expectancy have increased or been stagnant

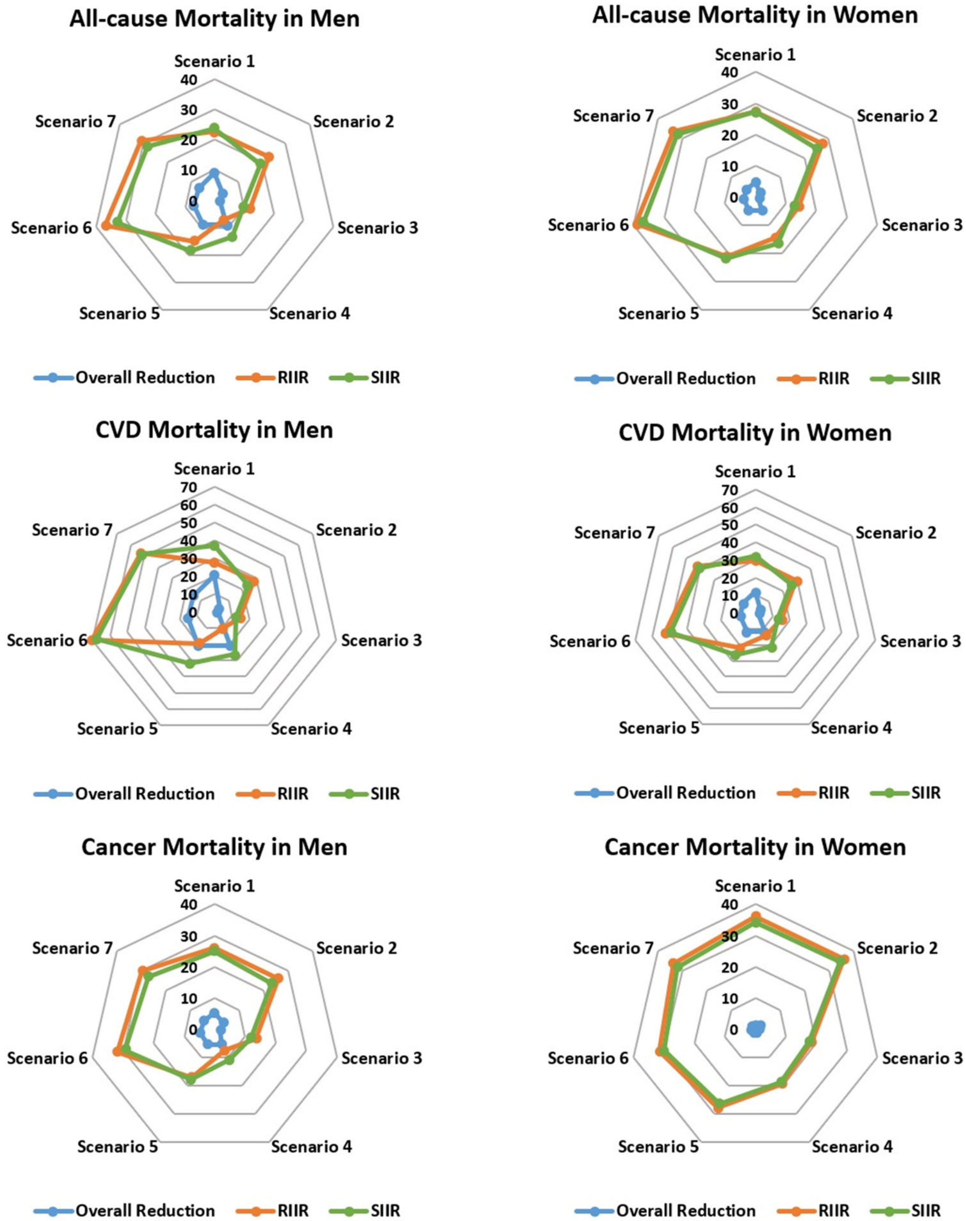

Fig. 2 The relationship between the reduction in overall population mortality risk and the reduction in mortality inequalities across the income groups, RII reduction (RIIR) and SII reduction (SIIR). The figure shows that the greatest relative reduction in overall mortality risk was found in Scenarios 1, 4, and 5, and the greatest reduction in relative index of inequality (RII) and slope index of inequality (SII) was found in Scenario 6, South Korea, 2018

despite the huge improvement in mortality measures during the past decades (Son et al. 2012; Bahk et al. 2017). With the lack of active labor market policies to reduce educational inequalities, the expansion of national health insurance was not enough to reduce the sustained educational inequalities in mortality (Bahk et al. 2017). It was suggested that macroeconomic factors and the expansion of neo-liberalism have contributed to increasing inequalities in life expectancy (Son et al. 2012). The economic crises in the late 1990s and in 2008 and associated structural adjustments in Korea might have played a substantial role in creating mortality inequalities and thus policies on such fundamental causes would meaningfully reduce mortality inequalities in South Korea.

A direct comparison of the results of this study with findings from other countries is difficult because of differences in the risk factors that were examined, socioeconomic position indicators, the social distribution of the risk factors, the age groups examined, cause-of-death structures, and methods for simulation. Despite such differences, this results of this study were not entirely dissimilar to those obtained in analyses from populations in the US and Europe (Alvarado et al. 2009; Hoffmann et al. 2013). Hoffmann and colleagues reported that, when the prevalence of major behaviors (physical activity, alcohol consumption, and smoking) in those with primary and low secondary education achieved the level of those with tertiary education, relative educational inequalities in all-cause mortality could be reduced by 26–35% among men and women aged 30+ from Belgium and the Czech Republic (Hoffmann et al. 2013). Our study presented a relative inequality reduction of 22.9% for men and 27.4% for women, respectively, for the same scenario (Scenario 2). A prior US study also found that absolute and relative inequalities in 10-year coronary heart disease risk by education and income could be reduced by 27–51% if the disadvantaged would achieve the levels of the advantaged (similar to Scenario 2 in this study) (Alvarado et al. 2009).

This study has limitations. First, beta coefficients and relative risks used in the simulation analyses were assumed to reflect causality. In this study, we used 12-year mortality follow-up data and excluded CVD or cancer patients identified at the 2002–2003 baseline. However, these methodological efforts to reduce the possibility of reverse causality are not optimal. We also examined all-cause mortality as an outcome measure, but some relationships between risk factors and outcomes (e.g., cholesterol and cancer mortality) might not be causal. Second, in this study we employed major five modifiable risk factors (hypertension, high cholesterol, diabetes, current smoking, and underweight/overweight). Considering that South Korea has relatively high proportions of mortality from diseases (e.g., tuberculosis, stomach cancer, liver disease, and suicide) that are not closely associated with these five risk factors, the inclusion of a different set of risk factors, such as early childhood infection, alcohol consumption, and mental health indicators, might produce better results for reducing mortality inequalities. Third, the use of complete-case analysis may be a limitation. The KNHANES is a nationally representative study, but the subset of participants with complete information on all risk factors may not be.

This study also has strengths. First, to our knowledge, this is the first study from an Asian country to examine the potential impacts of reducing inequalities in risk factors on mortality. Prior studies were conducted in Europe and in the US. Second, this study employed a large national longitudinal dataset, as well as nationally representative surveys on major modifiable risk factors, to obtain better country-specific estimates.

In conclusion, this study quantified the impact of reducing socioeconomic inequalities in five major modifiable risk factors on all-cause, CVD, and cancer mortality in South Korea. The analysis showed that a 10–20% reduction in all-cause mortality inequality could be achieved if the socioeconomic absolute gaps in risk factors were halved. Even, reversal of socioeconomic gradients in risk factors was expected to only reduce the mortality inequalities by less than 40%. Further reduction in mortality inequalities would need more aggressive policies on the social determinants of health.

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Authors' contribution Both authors were involved in the planning of the study, implementation of the study, and writing and approving the manuscript. HKL performed the data analysis under the consultation of YHK. Both authors interpreted the results. HKL drafted the manuscript. YHK reviewed and edited the manuscript.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethics approval The present study protocol was reviewed and approved by the Seoul National University Hospital Institutional Review Board (IRB No. E-1411-001-620).

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