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Area deprivation and premature cardiovascular mortality: a nationwide population-based study in South Korea

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ABSTRACT

Background Regional disparities in cardiovascular disease (CVD) burden exist. The effect of area deprivation, one of the possible explanations, still needs to be fully understood. This population-based study investigated the association between Area Deprivation Index (ADI) and CVD-related premature death.

Methods ADI was derived from 10 socioeconomic indicators in 250 South Korean municipalities using the 2020 Population and Housing Census data. Mortality rates for CVD and its subtypes, namely ischaemic heart diseases, other heart diseases and cerebrovascular diseases, in adults under 65 years were directly standardised by sex and age, referencing the total population structure. Municipalities were categorised by urbanicity, and adjustments for the number of hospitals and geographical area size were made using log-linear regression models.

Results The most deprived municipalities showed 41.6% excess mortality for CVD, 30.3% for ischaemic heart diseases, 60.7% for other heart diseases and 36.9% for cerebrovascular diseases compared with the least deprived municipalities. Even after adjusting for the number of hospitals per unit area, the association between ADI and premature CVD death was more significant in metropolitan areas than in other provinces. For each incremental increase in the continuous ADI, the adjusted mortality rate ratios were observed as 1.031 (95% CI, 1.020 to 1.043) in metropolitan areas and 1.009 (95% CI, 1.000 to 1.019) in other provinces. Additional multilevel analyses showed consistent findings of a higher risk in deprived areas.

Conclusion This study highlights a higher risk of premature cardiovascular death in socioeconomically disadvantaged areas. CVD prevention strategies should reflect regional characteristics and focus on reducing the burden in deprived metropolitan areas.

WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ Previous studies reported geographical variations in cardiovascular disease (CVD) mortality, suggesting regional differences in socioeconomic deprivation level as one of the possible explanations. Overall, area-level deprivation was associated with higher mortality rates to various degrees; however, most studies were conducted in Western countries such as the UK, the USA and France, and one study in Japan reported a weak negative correlation between deprivation and standardised CVD mortality.

WHAT THIS STUDY ADDS

⇒ Even in a setting where healthcare services are geographically and systematically accessible, regional socioeconomic deprivation was significantly associated with higher cardiovascular mortality in a dose–response manner. Notably, these associations were more prominent in metropolitan municipalities, implying the existence of health inequity within urban areas.

HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

⇒ Our findings suggest that implementing CVD prevention strategies should reflect regional characteristics, focusing on reducing CVD deaths in deprived regions; specifically, public health policy aiming to alleviate disparities in cardiovascular mortality due to socioeconomic deprivation in metropolitan areas and due to geographical accessibility to healthcare services in other provinces could potentially improve population health.

INTRODUCTION

Despite major progress in reducing cardiovascular disease (CVD) in recent decades, the burden of CVD continues to increase.[1 2] In-depth exploration has revealed that individual-level and regional-level social determinants are significantly associated with CVD.[3–6] Social determinants of cardiovascular health include educational attainment, socioeconomic status, access to healthcare and neighbourhood environment.[7] Previous ecological studies have determined how regional characteristics impact health-related behaviours and clinical consequences, including area-level socioeconomic conditions, neighbourhood cohesiveness, accessible green spaces and ambient air quality.[8–11] Area-level socioeconomic deprivation increases the risk of CVD incidence and recurrence.[12–14]

Since Townsend *et al* expanded the scope of deprivation to include the broader social and community contexts to which an individual, family or group belongs, several deprivation indices have been developed in various countries to quantify regional deprivation and measure health inequalities.[15] Examples include the Townsend Index, Carstairs Index, Multiple Deprivation Index in the UK, New Zealand Deprivation Index and Canadian Deprivation Index. These indices were formulated using multiple socioeconomic indicators from national census data while considering the specific context of each country.[16] By using these indices, research has captured regional disparities, which have been used to inform policy decisions and tailor interventions.[17]

Although South Korea (hereafter referred to as Korea) has a relatively low age-standardised CVD death rate compared with other countries and greater health equality due to offering of universal health coverage, regional disparities in CVD are present within the nation.[2 18–21] The substantial differences between regions in the early 1980s were reduced over time; however, specific areas—especially southeastern Korea—have had an unresolved and high risk of CVD mortality.[22] Another study on hospitalised patients with acute myocardial infarction showed consistent findings that the age-standardised incidence of CVD was more concentrated in specific regions.[23] Possible factors contributing to these regional disparities include urbanicity, healthcare accessibility and community socioeconomic conditions.[22 23] Previous research in Korea found a positive correlation between the Regional Deprivation Index and all-cause mortality.[19 20] However, evidence regarding the association of area deprivation with premature CVD mortality is limited.

Therefore, our study aimed to investigate the association between regional socioeconomic conditions, represented by the Area Deprivation Index (ADI), and premature CVD mortality in small administrative units across Korea. We hypothesised that, compared with residents of less deprived regions, those living in more deprived areas would have a higher rate of premature death from CVD, even after accounting for geographical accessibility to healthcare facilities. Furthermore, we anticipated that this association would manifest differently in urban versus rural areas.

METHODS

Geographical units

Korea has 17 first-tier administrative divisions, including 8 metropolitan cities (Seoul, Busan, Daegu, Incheon, Gwangju, Daejeon, Ulsan and Sejong) and 9 provinces (Gyeonggi-do, Gangwon-do, Chungcheongbuk-do, Chungcheongnam-do, Jeollabuk-do, Jeollanam-do, Gyeongsangbuk-do, Gyeongsangnam-do and Jeju-do). These are further divided into lower-level autonomies, such as si, gun or gu, hereafter collectively referred to as municipalities. Municipalities are the smallest administrative units in which most national statistics, including causes of death, are disclosed. Therefore, the unit of analysis in this study was the municipality. As of 2020, Korea had a total of 250 municipalities.

Area Deprivation Index (ADI)

ADI at the provincial and municipal level is reported every 5 years by the Busan Public Health Policy Institute.[24] The ADI is a composite score based on 10 socioeconomic indicators designed to quantify relative deprivation by region in Korea. These indicators include the proportion of (1) female household heads, (2) persons living alone, (3) households without a car, (4) divorced or widowed persons, (5) households with low socioeconomic status, (6) the older population than 65 years, (7) households with poor housing conditions, (8) individuals with less than secondary education, (9) households owning a house and (10) households dwelling in apartments. The index was developed by ensuring normality and standardising with z scores, followed by factor analysis. Notably, among the 10 indicators, the proportions of households owning a house and households dwelling in apartments exhibited opposing directions to that of other indicators in the factor analysis, as reflected in the summation formula. The details of the formulation are provided in online supplemental material S1 and previous studies.[24 25] A higher ADI represents higher deprivation in a region. We used the municipal-level ADI drawn from the 2020 Population and Housing Census data.

Other area-specific characteristics

In addition to area deprivation, healthcare accessibility is another critical domain of social determinants influencing CVD outcomes. To discern the impact of area deprivation from other area characteristics, we adjusted for the number of hospitals and the size of the area. General and tertiary hospitals are required to meet specified standards based on the Medical Service Act in Korea.[26] These hospitals should provide prompt and appropriate interventions for patients with CVD. We used the number of general and tertiary hospitals in the first quarter of 2020, as announced by the National Health Insurance Service. The total size of each municipality was obtained from the Ministry of Land, Infrastructure and Transport. The 2020 data were accessed from the Korean Statistical Information Service.[27]

Mortality

We obtained national mortality statistics for 2020 from the Microdata Integrated Service of Statistics Korea.[28] These statistics provide information on the sex, age, municipal-level residential area based on official resident registration, and cause of death for each reported case. The cause of death was provided from the list of 104 causes corresponding to the Mortality Tabulation List of the International Classification of Diseases 10th Revision (ICD-10). Premature CVD death was defined as those resulting from any CVD (ICD-10, I00–I99) occurring in adults aged 20–65 years. Subtypes of CVD deaths, including ischaemic heart diseases (I20–I25), other heart diseases (I00–I13, I26–I51) and cerebrovascular diseases (I60–I69), were also investigated.

All municipal death rates were directly standardised for sex and age using the total population structure of the same year (2020) as the standard population. The standardised mortality ratio (SMR) was calculated as the standardised rate ratio for each region to national mortality. For instance, an SMR above 1 indicates a higher CVD mortality rate in a given municipality than that in the entirety of Korea.

Statistical analysis

The associations between regional deprivation and mortality were assessed using multiple measures. First, the deprivation index was divided into quintiles, and SMRs were compared for each quintile category. The 95% CIs were calculated using the observed and expected death variances based on the Poisson distribution. Second, we plotted continuous deprivation indices and sex-standardised and age-standardised mortality and obtained correlation coefficients through the Pearson correlation analysis. Third, log-linear regression models were used to assess the association between ADI and sex-standardised and age-standardised mortality for total CVD, ischaemic heart diseases, other heart diseases and cerebrovascular diseases. Risk ratios were obtained by exponentiating the coefficients in the log-linear regression models, referring to the mortality increase per increment of deprivation.

Considering the differences in other area-specific characteristics, the number of hospitals and the size of each municipality were adjusted; one model was separately adjusted for the number of general hospitals, the number of tertiary hospitals and the size of a municipality, while the other model was adjusted for a composite variable with the number of hospitals per unit area (the sum of general hospitals and tertiary hospitals divided by the size of a municipality, per square kilometre). Furthermore, identical analyses were repeated after stratification into municipalities in metropolitan cities and those in other provinces.

Additionally, multiple sensitivity analyses were conducted. First, given the hierarchical structure of our analysis unit, we investigated associations at the provincial level in two ways: (1) the data were simply aggregated and analysed accordingly and (2) the possibility of a random effect of the provinces was contemplated[29]; therefore, we assessed the intraclass correlation coefficients (ICCs) and performed multilevel analyses. In the two-level log-linear models, municipal deprivations and other area characteristics were included as level 1 variables, while the code for the provinces to which each municipality belongs was considered a level 2 variable. Second, recognising the significant variation in CVD mortality by sex and age, we conducted identical analyses separately for each sex and age group. Third, the primary analyses used data from 2020, a year globally affected by COVID-19. For the sensitivity analyses, we used data from all available years. Last, we examined associations between each indicator incorporated in ADI and CVD mortality.

All analyses were performed using SAS V.9.4 and R V.4.2.2 (R Foundation for Statistical Computing, Vienna, Austria).

RESULTS

The ADI of municipalities in Korea ranged from −17.74 (least deprived, Suji-gu and Yongin-si in Gyeonggi-do) to 13.55 (most deprived, Sinan-gun in Jeollanam-do) (online supplemental table S1). The sex-standardised and age-standardised CVD mortality rate per 100 000 person-years was 30.14 for the entire country, ranging from 9.13 (Suji-gu and Yongin-si in Gyeonggi-do) to 73.18 (Cheorwon-gun in Gangwon-do). Figure 1 presents nationwide maps coloured according to deprivation and standardised CVD mortality quintiles.[30] A diagonal pattern was observed linking the Southwest and the Middle East, where a significant level of deprivation was present. While municipalities in metropolitan cities seem less deprived than those in other regions, a closer examination revealed prominent socioeconomic gradients within these areas. Similarly, CVD deaths were more concentrated in rural areas, but mortality rates were higher in specific municipalities within metropolitan areas.

Figure 2 shows the gradual associations between the categorised ADI and premature CVD mortality. In the higher quintiles of deprivation, the mortality rates of total CVD, ischaemic heart diseases, other heart diseases and cerebrovascular diseases were higher than those observed in the lower quintiles. In comparison to the least deprived municipalities (Q1), the most deprived ones (Q5) showed a relative excess mortality of 1.416 (95% CI, 1.257 to 1.596) for total CVD, 1.303 (95% CI, 1.065 to 1.595) for ischaemic heart diseases, 1.607 (95% CI, 1.261 to 2.047) for other heart diseases and 1.369 (95% CI, 1.129 to 1.659) for cerebrovascular diseases. Figure 3 depicts the correlation between the continuous ADI and standardised total CVD mortality in municipalities by urbanicity. When divided into metropolitan cities and other provinces, the correlation coefficient was 0.58 in metropolitan municipalities and 0.28 in provincial municipalities. Moreover, area deprivation accounted for 33.6% and 7.8% of the variance in total CVD deaths in metropolitan and other regions, respectively. Similarly, when disaggregating into the subtypes of CVD, the correlations with all subtypes of CVD were more significant in metropolitan regions (online supplemental figure S1). In particular, the gradient was prominent in premature death from other heart diseases and cerebrovascular diseases in metropolitan areas.

Tables 1 and 2 present the results of the log-linear regression using the continuous ADI. In an unadjusted but sex-standardised and age-standardised model, the rate ratio of total CVD was 1.017 (95% CI, 1.011 to 1.024) for all regions, 1.033 (95% CI, 1.023 to 1.042) for metropolitan

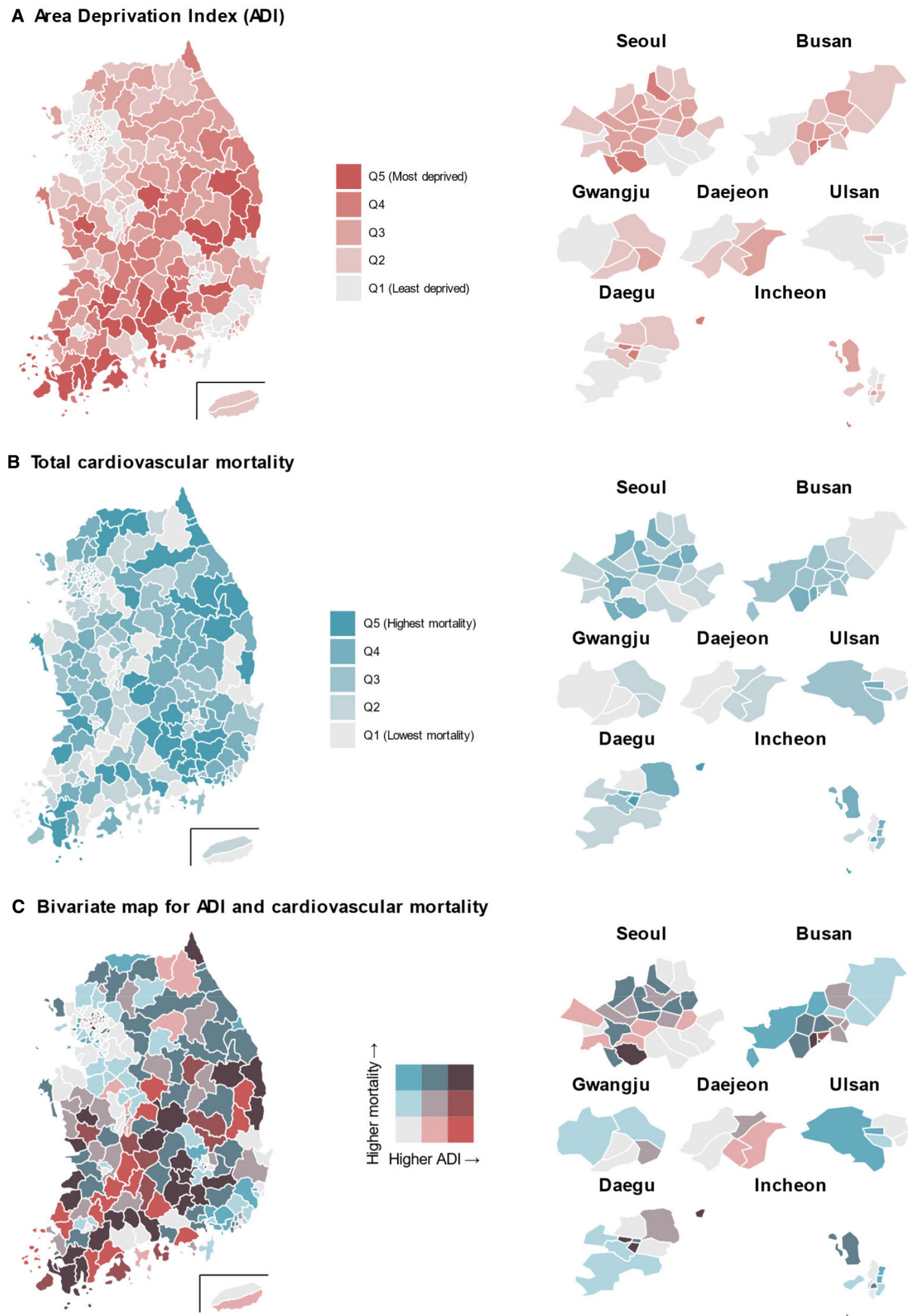

Figure 1 Nationwide maps coloured according to the quintiles of Area Deprivation Index and standardised CVD mortality. The 250 municipalities are coloured according to the quintiles of (A) ADI, (B) total cardiovascular mortality and (C) its combined set. The municipalities of seven metropolitan cities except for Sejong are shown enlarged to the right in each figure. Sejong is classified as a metropolitan city but consists of one municipality.

areas and 1.014 (95% CI, 1.006 to 1.022) for other provinces (table 1). The associations persisted after considering the number of hospitals and area size in models 1 and 2. When investigating the subtypes of CVD, the association between ADI and mortality from ischaemic heart diseases, other heart diseases and cerebrovascular diseases was more prominent in metropolitan areas than in other provinces (table 2); the adjusted rate ratios for ischaemic heart diseases were 1.025 (95% CI, 1.006 to 1.045) in metropolitan areas and 1.000 (95% CI, 0.983 to 1.017) in other provinces. Similarly, these were 1.042 (95% CI, 1.018 to 1.067) for other heart diseases

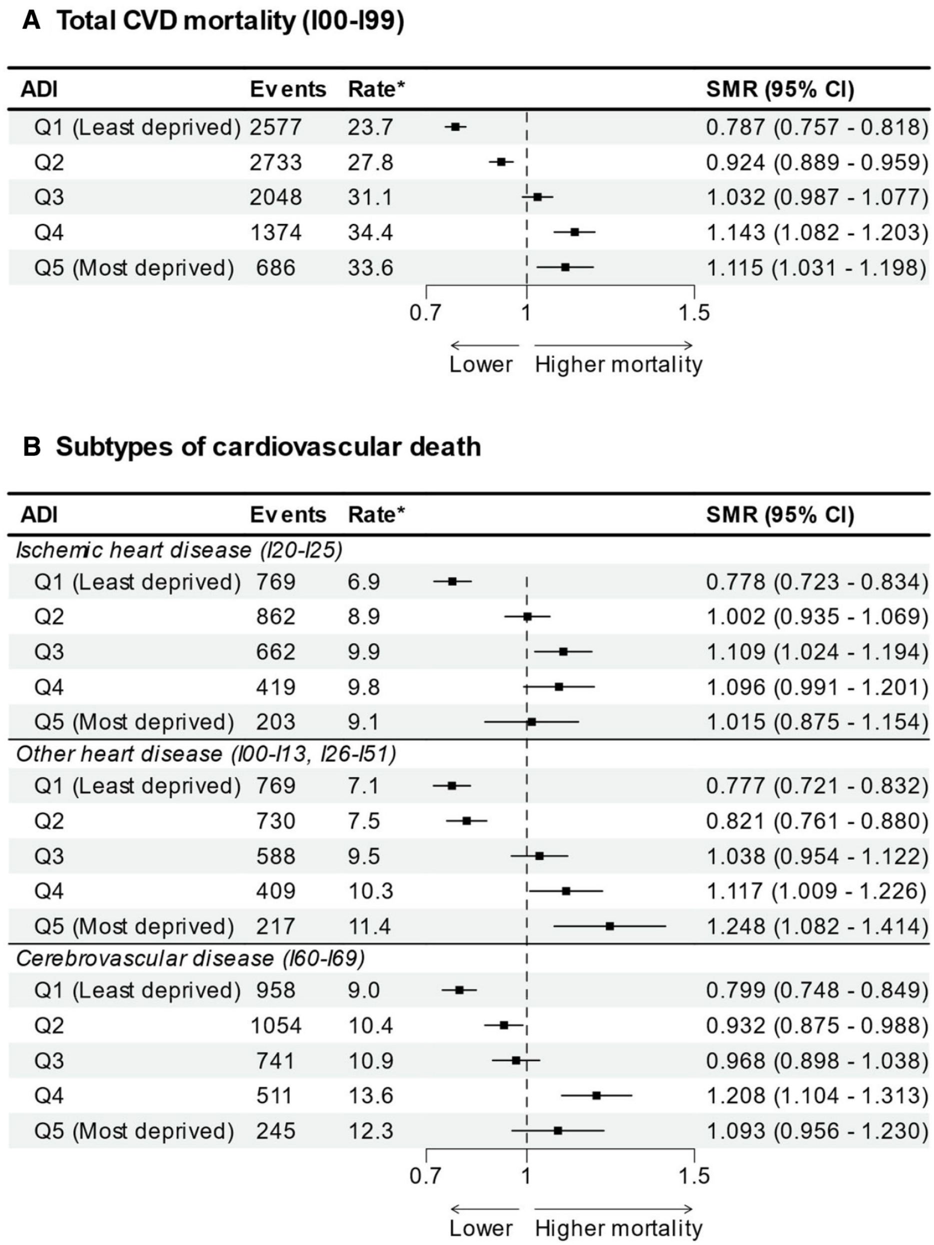

Figure 2 The association between ADI quintiles and (A) cardiovascular mortality and (B) its subtypes. The standardised mortality in the whole country was used as reference (standardised mortality ratio=1.000). The 95% CIs were calculated from the variances of the observed deaths and expected deaths based on the Poisson distribution. ADI, Area Deprivation Index; CVD, cardiovascular disease.

and 1.034 (95% CI, 1.019 to 1.050) for cerebrovascular diseases in metropolitan regions, while those in other provinces were 1.018 (95% CI, 0.997 to 1.039) and 1.010 (95% CI, 0.997 to 1.024), respectively.

In sensitivity analyses, the aggregated data showed that deprivation was positively associated with cerebrovascular disease mortality at the provincial level, but no other significant associations were observed (online supplemental table 2). A multilevel analysis was also conducted, accounting for the random effect of belonging to a province. The ICC indicated that 11% of the variability in mortality was attributed to provinces, with 89% associated with municipalities. The multilevel log-linear analyses consistently indicated an association between premature CVD mortality and area deprivation, with a stronger correlation observed in metropolitan areas (online supplemental table 3). Sex-specific analyses demonstrated that, despite relatively weak statistical significance in females, possibly due to the small number of events, the association between ADI and CVD mortality was consistently observed in both males and females (online supplemental table 4, figure 2). Similarly, the stratification by age showed that a gradual association is more prominent in the older age group with more events (online supplemental figure 3). Analyses for the years of 2005, 2010 and 2015 consistently revealed similar results (online supplemental figure 4). Each indicator incorporated in ADI was independently

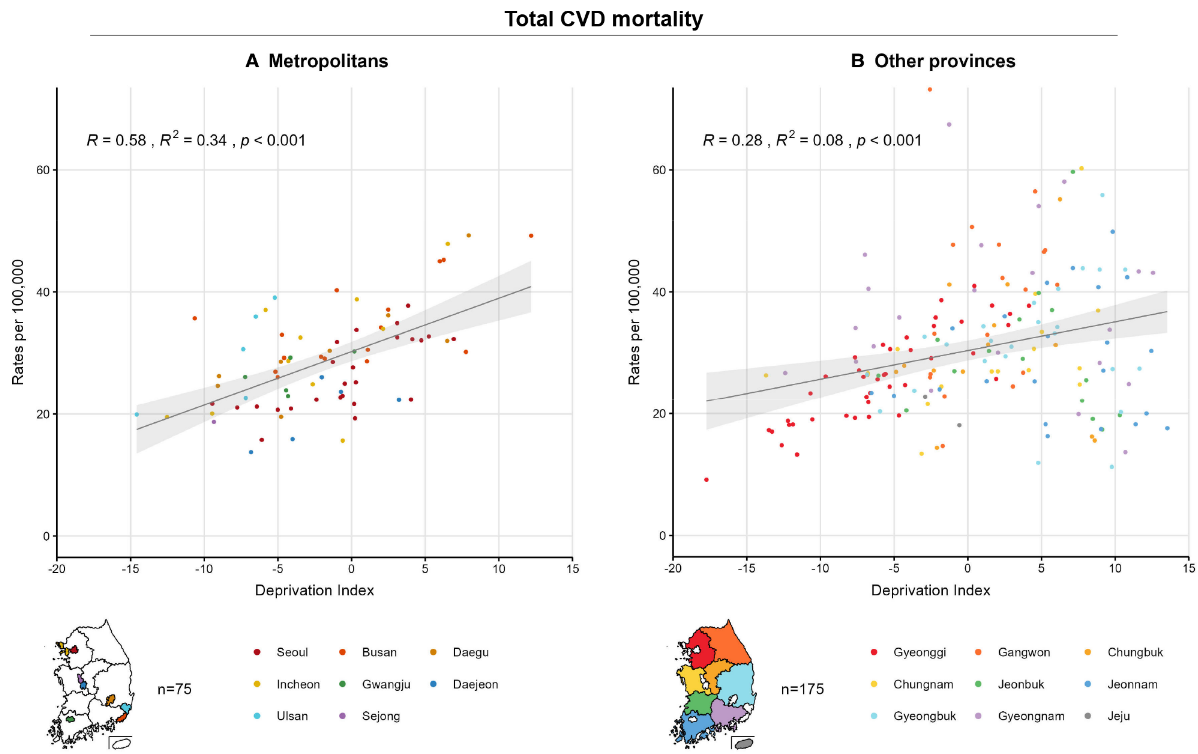

Figure 3 Area Deprivation Index and sex-standardised and age-standardised mortality rate per 100 000 at the municipal level. There were 75 municipalities in 8 metropolitan cities, and 175 in 9 provinces. The grey line represents a trend line based on linear regression, and the band for a 95% CI. CVD, cardiovascular disease.

examined. The proportions of individuals with less than secondary education and divorced or widowed persons were strongly correlated with CVD mortality in all regions (online supplemental table 5, figure 5).

DISCUSSION

We investigated the association between a municipal-level ADI and premature CVD mortality. More deprived regions are associated with an elevated mortality rate from premature CVD. When stratifying by urbanicity, we found that area deprivation is more associated with the outcomes in metropolitan regions than in other provinces. These associations persisted even after adjusting for the number of hospitals and area size.

Our findings are consistent with those of the existing literature, highlighting the association between regional socioeconomic conditions and CVD mortality despite variations in geographical units, deprivation indices and research designs across different studies. A cross-sectional study in the USA showed a significant association between ADI and cardiovascular premature mortality at the county level, while explaining 44% of county variability in cardiovascular mortality.[31] Similarly, a UK cohort study followed up 3924 men aged 60–79 years for 12 years and conducted a multilevel analysis.[32] After adjusting for individual socioeconomic status, smoking and drinking status, physical activity and body mass index, significantly higher odds of CVD mortality were observed in the more

Table 1 The association between Area Deprivation Index and total cardiovascular mortality

	Rate ratio* (95% CI)		
	Unadjusted	**Model 1**	**Model 2**
All regions	1.017 (1.011 to 1.024)	1.013 (1.005 to 1.022)	1.016 (1.009 to 1.023)
Metropolitans	1.033 (1.023 to 1.042)	1.035 (1.025 to 1.046)	1.031 (1.020 to 1.043)
Other provinces	1.014 (1.006 to 1.022)	1.006 (0.995 to 1.017)	1.009 (1.000 to 1.019)

Model 1 was adjusted for the number of general hospitals, the number of tertiary hospitals and the size of the municipality, in addition to standardisation for sex and age.
Model 2 was adjusted for the composite variable by dividing the sum of general hospitals and tertiary hospitals by the size of the municipality.
*Rate ratio is the exponentiated coefficient in log-linear regression between continuous deprivation index and sex-standardised and age-standardised mortality rate.

Table 2 The association between Area Deprivation Index and mortality from cardiovascular disease subtypes

	Rate ratio* (95% CI)		
	Unadjusted	**Model 1**	**Model 2**
Ischaemic heart diseases			
All regions	1.011 (1.000 to 1.021)	1.002 (0.988 to 1.016)	1.005 (0.994 to 1.017)
Metropolitans	1.021 (1.005 to 1.038)	1.023 (1.006 to 1.042)	1.025 (1.006 to 1.045)
Other provinces	1.009 (0.996 to 1.022)	0.989 (0.970 to 1.009)	1.000 (0.983 to 1.017)
Other heart diseases			
All regions	1.024 (1.011 to 1.038)	1.023 (1.005 to 1.041)	1.029 (1.014 to 1.045)
Metropolitans	1.056 (1.033 to 1.080)	1.056 (1.030 to 1.082)	1.042 (1.018 to 1.067)
Other provinces	1.018 (1.001 to 1.035)	1.012 (0.989 to 1.036)	1.018 (0.997 to 1.039)
Cerebrovascular diseases			
All regions	1.019 (1.010 to 1.027)	1.016 (1.005 to 1.027)	1.016 (1.006 to 1.025)
Metropolitans	1.030 (1.017 to 1.043)	1.035 (1.021 to 1.049)	1.034 (1.019 to 1.050)
Other provinces	1.015 (1.005 to 1.026)	1.013 (0.998 to 1.029)	1.010 (0.997 to 1.024)

Model 1 was adjusted for the number of general hospitals, the number of tertiary hospitals and the size of the municipality, in addition to standardisation for sex and age.
Model 2 was adjusted for the composite variable by dividing the sum of general hospitals and tertiary hospitals by the size of the municipality.
*Rate ratio is the exponentiated coefficient in log-linear regression between continuous deprivation index and sex-standardised and age-standardised mortality rate.

deprived areas compared with less deprived areas. In France, the ratio of SMR in the most deprived area over that in the least deprived area was 1.27 for all-cause deaths and 1.31 for CVD deaths.[33] However, a Japanese study showed a weak negative correlation between municipal socioeconomic conditions and ischaemic heart disease mortality, possibly resulting from regional differences in urbanicity.[34]

In this context, we stratified the regions into metropolitan cities and other provinces to consider the distinct differences in area characteristics. Municipalities in metropolitan areas are smaller in size, are more densely populated and have easier access to public resources, including healthcare services, than those in other provinces. After stratification, the association between ADI and premature mortality was more substantial in metropolitan areas than in other provinces. Furthermore, the pronounced gradient in metropolitan cities remained evident after adjusting for other geographical factors influencing healthcare service accessibility, which are also key determinants of CVD. The significant association of area deprivation in urban settings can be attributed, in part, to increased exposure to adverse environments. Factors such as limited space for physical activity, increased accessibility to fast but low-quality food and elevated pollution levels may contribute to this phenomenon. For instance, one study found that regions with high unemployment rates were more often exposed to road traffic and that high traffic exposure was significantly associated with a higher risk of coronary calcification.[35] These findings imply a greater risk for urban residents in deprived areas. Another study in Korea pointed out that the previous urban advantage in CVD mortality has diminished; instead, the gap between and within cities has worsened.[36]

Moreover, adjusting for the number of healthcare facilities and the area size weakened the association between ADI and premature CVD mortality in other provinces but slightly increased those in metropolitan areas. This suggests that tailored regional strategies should be implemented to decrease the CVD burden. While socioeconomic gradient is significantly associated with CVD mortality in metropolitan cities, the distribution and accessibility of medical resources can be critical in non-metropolitan areas where healthcare facilities are likely to be more sparsely distributed.[37]

The association between area deprivation and cardiovascular mortality is multifactorial and cannot be attributed to a single specific mechanism. For instance, the collective resource model elucidated that direct material deprivation at the regional level results in insufficient collective resources such as public services, recreational facilities, social support and healthcare services in deprived areas, thereby affecting residents' health.[38] Wilkinson and Pickett's psychosocial model, on the other hand, emphasises that the perception of one's relative social status, whether accurate or not, can lead to increased exposure to unfavourable environments and physiological manifestations of negative emotions, such as chronic stress and a sense of helplessness.[39–41] Also, previous studies reported that the association between an unhealthy lifestyle and CVD mortality becomes more prominent with increasing levels of deprivation.[42 43]

This study had some limitations. First, temporal interpretations should be made with caution because of the cross-sectional design of this study. Although the outcome in this study was CVD death, and reverse causality was less likely, the cumulative effect of area deprivation could not be measured. Living in a deprived area for a certain period may have increased an individual's risk of CVD mortality. However, an individual facing imminent death may have had substantial medical expenses and moved to a more deprived area. This may also have been reflected in the higher number of deaths in less affluent areas. Second, we combined several national datasets collected in 2020, including the demographic structure based on midyear population registration, deprivation index from the 2020 census data and death information from the 2020 national death statistics. However, each dataset may have been collected during different periods in 2020, possibly leading to the omission of information on population immigration and emigration. Given the global impact of COVID-19 on public health in 2020, it may also influence our results, despite the high participation rate in the Census survey and the relative robustness of death statistics. We performed the sensitivity analyses for all available years and found consistent results. Finally, there may have been residual confounding due to unknown confounders, although we attempted to account for other regional characteristics through stratification and adjustment.

Despite these limitations, our study has implications for further studies and prevention strategies by examining the association between area deprivation and premature CVD deaths. The ecological approach used in this study allows for the consideration of regional variations and psychosocial effects that cannot be measured at the individual income level. As Wilkinson noted, socioeconomic inequalities at the regional level are affected by the difference in the degree of residential segregation between the rich and poor and their perception of deprivation in the broader societal context.[40] Furthermore, using the municipality as the unit of analysis is appropriate; the association was blurred when analysing at the provincial level in additional analyses. Aggregating the data into 17 provinces may have led to the omission of the social gradients in CVD mortality that were present at the municipal level. Another approach, a multilevel analysis confirmed a higher CVD mortality in deprived areas, as shown in the primary analysis.

Our findings indicate a significant association between area deprivation and premature CVD mortality rates, even after adjusting for geographical accessibility to healthcare facilities. Particularly, ADI was more correlated in metropolitan areas. This suggests that implementing CVD prevention strategies that reflect regional characteristics, with a focus on reducing socioeconomic gradient in metropolitan areas and increasing healthcare accessibility in other provinces, could potentially improve population health.

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Competing interests None declared.

Patient and public involvement Patients and/or the public were not involved in the design, or conduct, or reporting, or dissemination plans of this research.

Patient consent for publication Not applicable.

Ethics approval As this study used deidentified and aggregated data without intruding on individuals' confidentiality, we determined that institutional review board approval was not required. The Microdata Integrated Service of Statistics Korea provided deidentified mortality data after registration. Other information on regional characteristics was obtained as aggregated regional statistics from the Busan Public Health Policy Institute and the Korean Statistical Information Service.

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