Environment International 125 (2019) 51–57

Contents lists available at ScienceDirect

Environment International

journal homepage: www.elsevier.com/locate/envint

Association between urban green space and the risk of cardiovascular disease: A longitudinal study in seven Korean metropolitan areas

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ARTICLE INFO

Handling Editor: Yong-Guan Zhu

Keywords:
Cardiovascular disease
Urban green space
Urban planning policy
Cohort study
Epidemiology

ABSTRACT

Purpose: Few previous studies have investigated the association between urban green space and cardiovascular disease (CVD) within Asian populations. We aimed to determine the relationship between amount of green space in the residential environment and CVD within a large general Asian population in this population-based longitudinal study.
Methods: The study population consisted of 351,409 participants aged over 20 years extracted from the National Health Insurance Service National Sample Cohort. Data on newly-occurred CVD events were collected from hospital admission records for the period 1 January 2006 to 31 December 2013. Cox proportional hazards regression analysis was used for determining the risk of developing CVD according to urban green space coverage (% area), adjusting for a number of relevant confounders.
Results: Compared to those within the lowest quartile of green space coverage, those within the highest quartile of urban space had a reduced risk of total CVD (hazard ratio, HR 0.85, 95% confidence interval, CI 0.81–0.89), coronary heart disease (HR 0.83, 95% CI 0.78–0.89), acute myocardial infarction (HR 0.77, 95% CI 0.68–0.88), total stroke (HR 0.87, 95% CI 0.82–0.93) and ischemic stroke (HR 0.86, 95% CI 0.80–0.94), but not hemorrhagic stroke (HR 0.98, 95% CI 0.86–1.12). The risk-reducing effect of green space coverage was preserved after stratification according to sex, household income, and Charlson comorbidity index.
Conclusion: Residing in urban regions with greater green space coverage may lead to a reduced risk of CVD. Urban planning intervention policies that increase urban green space coverage could help to reduce the risk of CVD.

1. Introduction

Cardiovascular disease (CVD) is a major factor contributing to mortality worldwide. According to the Global Burden of Diseases, Injuries, and Risk Factors Study 2015 (GBD 2015), the age-standardized CVD mortality rate per 100,000 people is 285.5 (uncertainty interval, UI, 280.2–291.2) among an all-cause mortality rate of 850.1 (UI 838.3–862.4) (Wang and GBD 2015 Mortality and Causes of Death Collaborators, 2016). Therefore, it is important to find and control for CVD risk factors in order to reduce the global burden of CVD. There is evidence that the built environment, which is an important determinant of health and wellbeing, may contribute to the risk of CVD (Chow et al., 2009). Among characteristics of built environment, the risk of developing CVD has previously been shown to be inversely associated with amount of green space (Gascon et al., 2016; Tamosiunas et al., 2014; Villeneuve et al., 2012).

A number of mechanisms may underlie the association between urban green space and incidence of CVD. There is evidence that greener surroundings can increase physical activity (Mytton et al., 2012; Park et al., 2013) and physical activity is positively associated with cardiovascular health (Nocon et al., 2008). Previous studies have found greater amounts of green space to be positively related with metal health (Annerstedt et al., 2012; Astell-Burt et al., 2014; Feda et al., 2015; Wood et al., 2017). Finally, green space in urban areas lowers air temperature within certain boundary around itself (Bowler et al., 2010; Takebayashi, 2017), and can improve air quality (Liu and Shen, 2014; Selmi et al., 2016), and long-term exposure to air pollution has been related to higher CVD mortality (Pope et al., 2004). Evidence on the importance of green space in controlling air quality is in accordance with a systemic model of Shen and Lung, which indicates that green

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https://doi.org/10.1016/j.envint.2019.01.038
Received 21 March 2018; Received in revised form 14 January 2019; Accepted 15 January 2019
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infrastructure acts as an environmental moderator of air pollution and temperature, which then reduces CVD mortality (Shen and Lung, 2016).

A review of studies in Western countries found a significant reduction in the risk of CVD mortality among those living in areas with the greater amounts of green space (Gascon et al., 2016). A number of studies which have investigated the short term effect of exposure to urban green space compared to urban streets found a reduction in indicators of CVD risk factors for the green space group (Grazuleviciene et al., 2015; Lanki et al., 2017). Kardan et al. (2015) found that tree density in Toronto city center was inversely associated with cardiometabolic conditions including CVD and its risk factors (Kardan et al., 2015) and a northwest Florida study reported that lower amounts of green space was related to higher incidence of stroke mortality (Hu et al., 2008). In a cross-sectional study, Mitchell and Popham (2008) found that compared to the least income-deprived group, the most deprived group had a higher risk of CVD mortality in the lowest amounts of green space coverage (incidence rate ratio, IRR 2.19, 95% CI 2.04–2.34) and in the highest green space coverage (IRR 1.54, 95% CI 1.38–1.73) (Mitchell and Popham, 2008). A study which focused on parks and recreation spaces had an increased odds ratio (OR) of myocardial infarction (OR 1.1, 95% confidence interval, CI 1.02–1.18) but not total CVD (OR 0.98, 95% CI 1.44–1.52) (Chum and O'Campo, 2015). Richardson and Mitchell (2010) found that male participants living in areas with greater green space coverage had a decreased risk of CVD mortality compared to those living in areas with lower amounts of green space, but there was no difference observed for females (Richardson and Mitchell, 2010).

Previous studies found higher prevalence of stroke in Asian countries compared to Western countries due to higher incidence of hypertension and lower total cholesterol, which was accompanied by high salt and low fat intake (Nguyen et al., 2013; Ueshima et al., 2008). Although a number of studies investigating the association between urban green space and CVD exist, most studies focused on Western populations, indicating the need for population-based longitudinal studies investigating the association between urban green space and CVD within Asian populations. In a Japanese study, Takano et al. (2002) found higher five year survival of the elderly living near accessible green space (Takano et al., 2002). In Hong Kong, there were two studies showing that greater amounts of natural green space associated with lower CVD mortality (Wang et al., 2017; Xu et al., 2017). All of these previous studies had relatively small study population sizes or were cross-sectional in design, limiting the generalizability of the results. Therefore, in this longitudinal study within a large Asian population, we sought to investigate the risk of CVD according to amount of green space in the residential environment.

2. Methods

2.1. Study population

The study population was derived from the Korean National Health Insurance Service National Sample Cohort (NHIS-NSC). The NHIS offers insurance benefits for nearly every phase of life related to health services such as prevention, diagnosis, treatment, and rehabilitation. The sample cohort represents 2.2% of Koreans who had national health insurance in 2002 (Lee et al., 2017). The cohort data contains information of sociodemographic status (e.g. age, sex, household income, residential area), hospital admission records and results from health screening examinations (e.g. body mass index, blood pressure, fasting serum glucose, total cholesterol), including health behaviors (e.g. physical activity, smoking habit).

We extracted data for 476,985 participants living in seven Korean metropolitan cities from NHIS-NSC data obtained in 2005. Among them, 117,559 participants aged < 20 years old were excluded. A number of 1372 participants with missing values of parks or total land areas offered by the Ministry of Land, Infrastructure and Transport (MOLIT) were eliminated, since while merging NHIS-NSC and MOLIT data set resulted in several district codes offered by NHIS did not matching those of the MOLIT. Then, deaths of 1873 participants, and 4732 participants diagnosed with CVD before the index date of 1 January 2006, were respectively excluded, leaving a total study population of 351,409 individuals. The Seoul National University Hospital Institutional Review Board approved this study (IRB number: E-1803-045-928), and as the NHIS anonymized database according to their strict rules the need for prior consent of the study population was waived.

2.2. Measure of urban green space

The MOLIT provided Cadastral Statistics, which consist of the area and the number of land lot and are banded according to land categories including parks and green space. We used data collected in 2005 including area (m^2) and the number of parks and green space which were artificially designed facilities for the purpose of improving public health and recreation. Natural green space including fields, mountains, and forests were not included to limit urban green space to built environment. A total of 72 administrative districts of the seven metropolitan cities in Korea were matched with the metropolitan unit the participants home address sits in. District areas ranged from 2.8 km^2 to 755.0 km^2, with a mean of 55.1 km^2 (standard deviation, SD = 79.9 km^2). We defined urban green space coverage as the proportion (%) for each district. For the analysis urban green space was grouped into quartiles, with threshold values 0.0–0.34, 0.34–0.92, 0.94–2.33, 2.38–15.3. Urban green space area per capita was urban green space area divided by the number of people living in the district.

2.3. Cardiovascular disease outcomes

We designed a longitudinal study of 8 years follow-up from 1 January 2006 to 31 December 2013. The primary outcome variable, total CVD events, was defined according to International Classification of Diseases Tenth Revision (ICD-10) within NIHS-NCS treatment records. To identify CVD patients and mortality, we used International Statistical Classification of Diseased and Related Health Problems (ICD-10 codes) as follows: coronary heart disease (CHD, I20-I25), acute myocardial infarction (AMI, I21-I24), total stroke (I60-69), hemorrhagic stroke (I60-I62), and ischemic stroke (I63). Total CVD events were defined as upon 2 or more days of hospitalization or death from CVD.

2.4. Statistical analysis

We used Cox proportional hazards regression as the NHIS-NSC database is longitudinal with information on death dates, thus making the calculation of follow-up durations possible. Cox proportional hazards regression additionally considers the follow-up duration for each individual patient, thus providing a more accurate risk assessment via hazard ratios compared to logistic regression. The assumption of proportionality was graphically tested and verified using the Schoenfeld residual method. Since NHIS-NSC offering information year and month of death, we defined the first day of the month as date of death in order to use Cox proportional hazards model. Two multivariate models were established. Model 1 included adjustment for the following covariates in this study: age (grouped at 5 years intervals), sex, household income (4 quartiles depending on insurance premium), disability (3 categories: none, mild disability, serious disability), and Charlson comorbidity index (CCI, the index for preexisting diseases). In this study, CCI for individuals was calculated by diagnoses from 2002 to 2005 according to a previous study (Sundararajan et al., 2004). Model 2 was built on Model 1 including additional adjustment for data from health screening examinations. Among 351,409 participants, 113,576 (32.32%) participants of study population had all the information about body mass

Table 1
Descriptive characteristics of study population.

	Total	Urban green space coverage			
		First quartile (low)	Second quartile	Third quartile	Fourth quartile (high)
Urban green space coverage, mean (SD), %	1.68 (2.27)	0.18 (0.10)	0.65 (0.17)	1.58 (0.44)	4.47 (3.15)
Participants, N (%)	351,409 (100.00)	91,189 (25.95)	88,388 (25.15)	87,386 (24.87)	84,446 (24.03)
Age, years, N (%)					
20–29	78,540 (22.35)	20,267 (22.23)	19,439 (21.99)	19,396 (22.20)	19,438 (23.02)
30–39	86,217 (24.53)	21,079 (23.12)	22,653 (25.63)	21,634 (24.76)	20,851 (24.69)
40–49	82,474 (23.47)	20,682 (22.68)	20,826 (23.56)	21,335 (24.41)	19,631 (23.25)
50–59	53,455 (15.21)	14,395 (15.79)	13,236 (14.97)	12,777 (14.62)	13,047 (15.45)
≥ 60	50,723 (14.43)	14,766 (16.19)	12,234 (13.84)	12,244 (14.01)	11,479 (13.59)
Sex, N (%)					
Men	171,902 (48.92)	44,812 (49.14)	43,486 (49.20)	42,446 (48.57)	41,158 (48.74)
Women	179,507 (51.08)	46,377 (50.86)	44,902 (50.80)	44,940 (51.43)	43,288 (51.26)
Household income, N (%)					
First quartile (highest)	99,149 (28.21)	23,474 (25.74)	23,982 (17.13)	24,826 (28.41)	26,867 (31.82)
Second quartile	110,821 (31.54)	28,888 (31.68)	28,000 (31.68)	28,188 (32.26)	25,745 (30.49)
Third quartile	85,967 (24.46)	23,229 (25.47)	21,818 (24.68)	20,944 (23.97)	19,976 (23.66)
Fourth quartile (lowest)	55,472 (15.79)	15,598 (17.11)	14,588 (16.50)	13,428 (15.37)	11,858 (14.04)
Disability, N (%)					
Normal	337,900 (96.16)	87,453 (95.90)	85,041 (96.21)	84,011 (96,14)	81,395 (96.39)
Mild	3634 (1.03)	1018 (1.12)	867 (0.98)	940 (1.08)	809 (0.96)
Serious	9875 (2.81)	2718 (2.98)	2480 (2.81)	2435 (2.79)	2242 (2.65)
Charlson comorbidity index, N (%)					
0	214,873 (61.15)	55,067 (60.39)	53,837 (60.91)	53,474 (61.19)	52,495 (62.16)
1	87,391 (24.87)	22,706 (24.90)	22,149 (25.06)	21,860 (25.02)	20,676 (24.48)
≥ 2	49,145 (13.99)	13,416 (14.71)	12,402 (14.03)	12,052 (13.79)	11,275 (13.35)
Participants who underwent health screening examinations, N (%)	113,576 (100.00)	29,996 (26.41)	28,614 (25.19)	28,487 (25.08)	26,479 (23.31)
Body mass index, kg/m^2, mean (SD)	23.45 (3.14)	23.47 (3.12)	23.49 (3.14)	23.46 (3.14)	23.38 (3.16)
Systolic blood pressure, mmHg, mean (SD)	122.71 (16.66)	123.23 (16.69)	123.00 (16.70)	122.32 (16.56)	122.24 (16.64)
Total cholesterol, mg/dL, mean (SD)	194.01 (37.30)	194.17 (37.04)	193.85 (37.30)	193.74 (37.51)	194.307 (37.35)
Fasting serum glucose, mg/dL, mean (SD)	94.72 (26.22)	95.35 (25.61)	94.62 (28.02)	94.99 (25.66)	93.84 (25.43)
Smoking, N (%)					
Never smoker	76,156 (67.05)	20,081 (66.95)	19,036 (66.53)	19,245 (67.56)	17,794 (67.20)
Former smoker	5651 (4.98)	1423 (4.74)	1359 (4.75)	1477 (5.18)	1392 (5.26)
Current smoker	31,769 (27.97)	8492 (28.31)	8219 (28.72)	7765 (27.26)	7293 (27.54)
Physical activity, times per week, N (%)					
None	58,868 (51.83)	15,628 (52.10)	14,864 (51.95)	14,695 (51.58)	13,681 (51.67)
1–2	32,258 (28.40)	8289 (27.63)	8165 (28.53)	8233 (28.90)	7571 (28.59)
3–4	12,803 (11.27)	3309 (11.03)	3199 (11.18)	3159 (11.09)	3136 (11.84)
5–6	3046 (2.68)	775 (2.58)	744 (2.60)	761 (2.67)	766 (2.89)
7	6601 (5.81)	1995 (6.65)	1642 (5.74)	1639 (5.75)	1325 (5.00)
Alcohol consumption, times per week, N (%)					
None	57,666 (50.77)	15,527 (51.76)	14,449 (50.50)	14,324 (50.28)	13,366 (50.48)
< 1	22,901 (20.16)	5794 (19.32)	5790 (20.23)	5793 (20.34)	5524 (20.86)
1–2	23,021 (20.27)	5876 (19.59)	5838 (20.40)	5894 (20.69)	5413 (20.44)
3–4	7090 (6.24)	1926 (6.42)	1779 (6.22)	1809 (6.35)	1576 (5.95)
≥ 5	2898 (2.55)	873 (2.91)	758 (2.65)	667 (2.34)	600 (2.27)

Acronyms: N, number of people; SD, standard deviation.

index, blood pressure, total cholesterol, fasting serum glucose, smoking status (3 categories: never smoker, former smoker, current smoker), physical activity (5 categories: none, 1–2, 3–4, 5–6, 7, times per week), and alcohol consumption (5 categories: none, < 1, 1–2, 3–4, 5, times per week). The different sets of Cox regressions were undertaken with all participants based on Model 1, including using green space per capita as the green space metric, and participants who underwent health screening based on Model 1 and Model 2. The stratified analysis was undertaken only for the total CVD events. Data mining was carried out with SAS 9.4 (SAS Institute, Cary, NC, USA), and statistical analysis using STATA 13.0 (Stata Corp LP, College Station, TX, USA).

3. Results

Table 1 reports the average values of green space, coverage in total is 1.6% and those from the first to the fourth quartile are 0.2%, 0.7%, 1.6%, and 4.5%. The lowest income group accounts for 17.1% in the first quartile of green space coverage. The number of participants who underwent health screening examinations was 113,576, which accounts for 32.32% of total participants. The mean value of Body Mass Index (BMI) was 23.5 kg/m^2 and the proportion of participants who did not undertake physical activity was 51.8%. There were minimal variations in these variables across green space coverage quartiles as shown in Table 1.

Table 2 shows the reduced risk of developing CVD inversely associated with green space coverage based on Model 1. Compared to the participants in the first (lowest) green space quartile, those in the fourth (highest) green space quartile were found to have a reduced risk of CVD (HR 0.85, 95% CI 0.81–0.89, $p < 0.001$). Participants living in the greenest quartile were also found to have a reduced risk of coronary heart disease, CHD (HR 0.83, 95% CI 0.78–0.89, $p < 0.001$) and acute myocardial infarction, AMI (HR 0.77, 95% CI 0.68–0.88, $p < 0.001$). For participants living in the greenest quartile there was also a significant decreased risk of total stroke (HR 0.87, 95% CI 0.82–0.93, $p < 0.001$) and ischemic stroke (HR 0.86, 95% CI 0.80–0.94, $p < 0.001$), but not hemorrhagic stroke (HR 0.98, 95% CI 0.86–1.12, $p = 0.901$). Cox regressions using green space area per capita show weaker trends compared to those observed for the green space coverage (Appendix A).

The significant trends were found from adjusted Cox regression

Table 2
Association of urban green space coverage with the risk of CVD.

	Urban green space coverage				p for trend
	First quartile (low)	Second quartile	Third quartile	Fourth quartile (high)	
Cardiovascular disease					
Events, N (%)	4272 (4.68)	3454 (3.91)	3414 (3.91)	3113 (3.69)	
Person-years	699,357	682,179	674,561	653,493	
aHR (95% CI)	1.00 (Reference)	0.90 (0.86–0.94)	0.89 (0.85–0.93)	0.85 (0.81–0.89)	< 0.001
Coronary heart disease					
Events, N (%)	2073 (2.27)	1588 (1.80)	1645 (1.88)	1483 (1.76)	
Person-years	705,572	687,699	679,647	658,301	
aHR (95% CI)	1.00 (Reference)	0.85 (0.80–0.91)	0.89 (0.83–0.94)	0.83 (0.78–0.89)	< 0.001
Acute myocardial infarction					
Events, N (%)	583 (0.64)	427 (0.48)	420 (0.48)	384 (0.45)	
Person-years	710,814	691,929	684,169	662,341	
aHR (95% CI)	1.00 (Reference)	0.82 (0.73–0.93)	0.81 (0.71–0.92)	0.77 (0.68–0.88)	< 0.001
Total stroke					
Events, N (%)	2449 (2.69)	2021 (2.29)	1945 (2.23)	1807 (2.14)	
Person-years	705,508	687,118	679,727	658,052	
aHR (95% CI)	1.00 (Reference)	0.93 (0.87–0.98)	0.89 (0.84–0.95)	0.87 (0.82–0.93)	< 0.001
Ischemic stroke					
Events, N (%)	1391 (1.53)	1156 (1.31)	1056 (1.21)	1001 (1.19)	
Person-years	708,272	689,353	682,085	660,207	
aHR (95% CI)	1.00 (Reference)	0.95 (0.88–1.03)	0.86 (0.80–0.93)	0.86 (0.80–0.94)	< 0.001
Hemorrhagic stroke					
Events, N (%)	503 (0.55)	429 (0.49)	447 (0.51)	423 (0.50)	
Person-years	710,936	691,941	684,151	662,182	
aHR (95% CI)	1.00 (Reference)	0.94 (0.83–1.07)	0.98 (0.86–1.11)	0.98 (0.86–1.12)	0.901

Urban green space coverage was defined as the area of parks and artificially designed green space divided by the area of residential districts. Hazard ratio calculated by Cox proportional hazards regression analysis after adjustments for age, sex, income, disability, and Charlson comorbidity index.
Acronyms: N, number of people; aHR, adjusted hazard ratio; CI, confidential interval.

models constructed for participants who had health screening (Model 2). Compared to participants living in the first quartile, those in the fourth green space quartile were found to have a reduced risk of total CVD (HR 0.83, 95% CI 0.76–0.90, $p < 0.001$). Participants living in the greenest quartile were found to have a decreased risk of CHD (HR 0.78, 95% CI 0.70–0.87, $p < 0.001$) and AMI (HR 0.71, 95% CI 0.57–0.89, $p < 0.01$). For participants living in the greenest quartile, the risks of total stroke (HR 0.88, 95% CI 0.79–0.98, $p < 0.01$) and ischemic stroke (HR 0.88, 95% CI 0.76–1.01, $p < 0.01$) were significantly reduced, but not hemorrhagic stroke (HR 1.17, 95% CI 0.93–1.47, $p = 0.200$). The trends from Model 2 were preserved from Model 1 after adjustment for data from health screening examinations.

Table 3 shows a series of stratified analyses on age, sex, income, and Charlson Comorbidity Index (CCI). For participants aged over 40, those living in the greenest quartile were found to have a significantly lower risk of total CVD (aged 40–59, HR 0.81, 95% CI 0.75–0.87, $p < 0.001$; age ≥ 60, HR 0.89, 95% CI 0.84–0.95, $p < 0.001$), but for those aged under 40 years, the association between green space coverage and total CVD was not significant (HR 0.88, 95% CI 0.73–1.05, $p = 0.391$). Both male and female populations were found to have a reduced risk of CVD in the fourth quartile (men, HR 0.86, 95% CI 0.80–0.92, $p < 0.001$; women, HR 0.85, 95% CI 0.79–0.91, $p < 0.001$). Participants in both income groups were found to have a statistically significant trend of total CVD risk with green space coverage (upper, HR 0.89, 95% CI 0.84–0.94, $p < 0.001$; lower, HR 0.79, 95% CI 0.74–0.85, $p < 0.001$). There was a significant decreasing trend of total CVD for both those who had no history of pre-existing disease (HR 0.86, 95% CI 0.80–0.92, $p < 0.001$) and those who had pre-existing disease (HR 0.86, 95% CI 0.81–0.91, $p < 0.001$).

Table 3
Stratified analysis on the association of urban green space coverage with the risk of CVD.

		Urban green space coverage				p for trend
		First quartile (low)	Second quartile	Third quartile	Fourth quartile (high)	
Age	aHR (95% CI)					
	20–39 years	1.00 (Reference)	1.05 (0.88–1.24)	1.15 (0.98–1.37)	0.88 (0.73–1.05)	0.391
	40–59 years	1.00 (Reference)	0.86 (0.80–0.93)	0.85 (0.79–0.92)	0.81 (0.75–0.87)	< 0.001
	≥ 60 years	1.00 (Reference)	0.91 (0.85–0.96)	0.89 (0.83–0.94)	0.89 (0.84–0.95)	< 0.001
Sex	aHR (95% CI)					
	Men	1.00 (Reference)	0.90 (0.84–0.96)	0.88 (0.82–0.94)	0.86 (0.80–0.92)	< 0.001
	Women	1.00 (Reference)	0.91 (0.85–0.97)	0.91 (0.84–0.97)	0.85 (0.79–0.91)	< 0.001
Household income	aHR (95% CI)					
	Upper half	1.00 (Reference)	0.91 (0.86–0.97)	0.90 (0.85–0.95)	0.89 (0.84–0.94)	< 0.001
	Lower half	1.00 (Reference)	0.89 (0.83–0.95)	0.88 (0.82–0.95)	0.79 (0.74–0.85)	< 0.001
CCI	aHR (95% CI)					
	0	1.00 (Reference)	0.89 (0.83–0.96)	0.91 (0.85–0.98)	0.86 (0.80–0.92)	< 0.001
	≥ 1	1.00 (Reference)	0.91 (0.86–0.97)	0.88 (0.83–0.93)	0.86 (0.81–0.91)	< 0.001

Urban green space coverage was defined as the area of parks and artificially designed green space divided by the area of residential districts. Hazard ratio calculated by Cox proportional hazards regression analysis after adjustments for age, sex, income, disability, and Charlson comorbidity index.
Acronyms: aHR, adjusted hazard ratio; CI, confidential interval.

4. Discussion

Our analyses found that the participants residing in areas with greater green space coverage had a reduced risk of cardiovascular disease (CVD), coronary heart disease (CHD), acute myocardial infarction (AMI), total stroke, and ischemic stroke, but not hemorrhagic stroke. For CVD risk the trend was found to hold true upon stratification by age, sex, household income, and pre-existing disease. To our knowledge this is the first study to show an association between amount of area-level residential green space and risk of individual-level CVD events for a large general population in Asia, specifically a reduced risk of CVD for individuals living in the greenest areas compared to those living in the least green areas.

Similar to our results, a Canadian cohort study found that amount of neighborhood green space measured in Normalized Difference Vegetation Index (NDVI) had a positive effect on CVD mortality (rate ratio, RR 0.94, 95% CI 0.92–0.96) and ischemic heart disease mortality (RR 0.94, 95% CI 0.92–0.97) (Villeneuve et al., 2012). Another cohort study in Lithuania reported that participants in the third tertile of distance to green space were found to have higher hazard ratio (HR) of total CVD (HR 1.36, 95% CI 1.03–1.80) than those within the first tertile. Further, participants living at a greater distance from green space and who did not use parks were found to have a higher risk of CVD (HR 1.66 95% CI 1.01–2.73) than those living near green space and park users (Tamosiunas et al., 2014). On the other hand, three ecological studies found no association between green space coverage and CVD mortality (Bixby et al., 2015; Richardson et al., 2010; Richardson et al., 2012). Although the reasons for the discrepancy in the results are unclear, one possible explanation may come from ecological study designs, which led to use area-level covariates and health outcomes in contrast to those of our study at individual-level. These studies used cross-sectional study designs, which could not determine causality between exposure variables and health outcomes, while our longitudinal study followed up the cohort over time to investigate the causal relationship between them. Similar to the results from Western populations, an elderly cohort study in Hong Kong found that green space coverage in residential areas was inversely associated with CVD mortality (HR 0.887, 95% CI 0.817–0.963) and stroke (HR 0.661, 95% CI 0.524–0.835) (Wang et al., 2017). However, this study was limited in the relatively small number of participants (3544 people) and its restriction to an older population (=65 years).

Unlike other CVD results from this study, the lack of a significant trend for hemorrhagic stroke was possibly due to insufficient number of events to detect a statistically significant trend. Future studies with longer follow-up durations are needed in order to gather more hemorrhagic stroke cases to validate the findings from this study. The results from stratified analyses differ from previous studies in some aspects (Table 3). First, there was no significant trend for young adults aged under 40, and this was probably due to the small number of CVD events. Second, our analyses stratified by sex found significant trends for both groups, whereas in an ecological study undertaken for a UK population sample Richardson and Mitchell (2010) found that amount of green space was inversely related with the risk of CVD mortality in male participants only (Richardson and Mitchell, 2010). These differences may be due to differences in study design. Finally, the significant trends were observed for both upper and lower income groups, but the trend was stronger for the lower income group. Several previous studies found the significant trends for lower income group only. Mobley et al. (2006) observed that low income women residing in highly mixed land were found to have a lower risk of CHD (Mobley et al., 2006). Another ecological study found a significant association between green space coverage and CVD mortality for lower socioeconomic group (Silveira and Junger, 2018). To our knowledge, there were few previous studies which found significant associations in both income groups.

The main strength of our study is that, in contrast to previous studies that were of ecological nature or cross-sectional design, we determined the association of area-level green space coverage with individual-level CVD outcomes in this longitudinal cohort. Furthermore, we had a large population sample of over 350,000 participants residing in seven large cities extracted from a nationwide database, and the individual-level covariates representing the participants not only depends on self-reported questionnaire data, but on measures from health examinations. Thus, it was possible to adjust for confounding effects of risk factors of CVD such as BMI, blood pressure, fasting serum glucose and total cholesterol. Additionally, unlike other studies which focused on seniors, or genders and income groups, this study found significant associations between urban green space and CVD outcome of population aged over 40, for both sexes, and upper and lower income groups.

There are several limitations to consider when interpreting the results from our study. First, our study population is limited to urban metropolitan areas. Therefore, future studies investigating the effect of green space coverage on CVD among rural regions are needed. Second, in this study urban green space was defined as urban parks and green areas and did not include fields and forests, as we aimed to investigate the effect of built environment. Third, our data sources lack precise spatial properties. Our data derived from NHIS-NSC offering district codes of participants without exact address to preserve participants' anonymity. Thus, it was less likely to match residential district codes from NHIS-NSC to address from green space data at the same level, even if there was green space data including exact address and GIS map. This study followed the previous studies using district codes of participants and environmental data (Kim et al., 2016; Min et al., 2018). Finally, we could not adjust for additional and potentially important social and environmental covariates such as leisure time, particulate matter, safety and noise. Additionally, our database did not include the information of individual-level dietary intake which might have relationship with urban green space and the risk of CVD and needs to be considered. Since Asian populations found to be influenced by different risk factors including salt and fat intake for CVD from those for Western populations (Ueshima et al., 2008), future studies that include these potential confounders are needed to validate the findings of this study.

5. Conclusion

This study suggests that residing in big cities with more green space may lead to a reduced risk of CVD. The association was preserved for participants aged over 40, male and female, and high and low income groups. Further studies are needed to investigate the effect of improved green space usage and area-level changes in green space coverage. Our findings support the importance of urban planning policies that increase green infrastructure and green space coverage in urban areas, in terms of the prevention of CVD.

Acknowledgements

S Seo contributed to writing the manuscripts, acquisition, analysis and interpretation of data. S Choi contributed to drafting the manuscripts, acquisition and interpretation of data. All authors contributed to study concept and design, critical revision of the manuscript, and confirmed the final revision of the manuscripts. Dr. SM Park is responsible for the integrity of data and the accuracy of analysis.

Declarations of interest

None.

Funding

This study was funded by the Data Science Research Project 2018 by the Seoul National University Big Data Institute (grant number: 2018-0000) and Seoul National University Hospital Research Fund (grant number: 04-2018-0370). S Choi, K Kim, and SM Kim received a BK-21 Plus Education Program provided by the National Research Foundation of Korea, South Korea.

Appendix A. Association of urban green space area per capita with the risk of CVD

	Urban green space area per capita				*p* for trend
	First quartile (Low)	Second quartile	Third quartile	Fourth quartile (High)	
Cardiovascular disease					
Events, N (%)	4054 (4.52)	3510 (3.97)	3450 (3.75)	3239 (3.98)	
Person-years	687,931	681,284	711,289	629,086	
aHR (95% CI)	1.00 (Reference)	0.94 (0.90–0.98)	0.89 (0.85–0.93)	0.96 (0.92–1.01)	0.007
Coronary heart disease					
Events, N (%)	2024 (2.26)	1590 (1.80)	1601 (1.74)	1574 (1.93)	
Person-years	693,762	686,924	716,753	633,779	
aHR (95% CI)	1.00 (Reference)	0.85 (0.80–0.91)	0.82 (0.77–0.87)	0.93 (0.87–0.99)	0.004
Acute myocardial infarction					
Events, N (%)	547 (0.61)	406 (0.46)	462 (0.50)	399 (0.49)	
Person-years	698,954	691,307	720,989	638,004	
aHR (95% CI)	1.00 (Reference)	0.81 (0.71–0.92)	0.88 (0.78–1.01)	0.89 (0.78–1.01)	0.130
Total stroke					
Events, N (%)	2262 (2.52)	2092 (2.37)	2028 (2.20)	1840 (2.26)	
Person-years	693,965	686,324	716,219	633,897	
aHR (95% CI)	1.00 (Reference)	1.01 (0.95–1.07)	0.94 (0.89–1.00)	0.98 (0.92–1.05)	0.228
Ischemic stroke					
Events, N (%)	1316 (1.47)	1137 (1.29)	1126 (1.22)	1025 (1.26)	
Person-years	696,398	688,843	718,632	636,043	
aHR (95% CI)	1.00 (Reference)	0.95 (0.88–1.03)	0.91 (0.84–0.98)	0.95 (0.88–1.03)	0.116
Hemorrhagic stroke					
Events, N (%)	459 (0.51)	467 (0.53)	460 (0.50)	416 (0.51)	
Person-years	699,131	691,174	720,933	637,973	
aHR (95% CI)	1.00 (Reference)	1.08 (0.95–1.23)	1.04 (0.91–1.18)	1.08 (0.95–1.23)	0.373

Urban green space area per capita was defined as the area of parks and artificially designed green space divided by the number of people in residential districts.
Hazard ratio calculated by Cox proportional hazards regression analysis after adjustments for age, sex, income, disability, and Charlson comorbidity index.
Acronyms: N, number of people; aHR, adjusted hazard ratio; CI, confidential interval

Appendix B. Association of urban green space coverage with the risk of CVD among people who underwent health screening examinations

	Urban green space coverage				*p* for trend
	First quartile (low)	Second quartile	Third quartile	Fourth quartile (high)	
Cardiovascular disease					
Events, N (%)	1543 (5.14)	1228 (4.29)	1121 (3.94)	1003 (3.79)	
Person-years	231,031	221,431	221,098	205,758	
Model 1 aHR (95% CI)	1.00 (Reference)	0.89 (0.83–0.97)	0.82 (0.76–0.88)	0.82 (0.76–0.89)	< 0.001
Model 2 aHR (95% CI)	1.00 (Reference)	0.89 (0.83–0.96)	0.82 (0.76–0.89)	0.83 (0.76–0.90)	< 0.001
Coronary heart disease					
Events, N (%)	812 (2.71)	608 (2.12)	586 (2.06)	506 (1.91)	
Person-years	232,267	223,480	222,783	207,392	
Model 1 aHR (95% CI)	1.00 (Reference)	0.83 (0.75–0.93)	0.81 (0.73–0.90)	0.78 (0.70–0.87)	< 0.001
Model 2 aHR (95% CI)	1.00 (Reference)	0.83 (0.75–0.92)	0.81 (0.73–0.90)	0.78 (0.70–0.87)	< 0.001
Acute myocardial infarction					
Events, N (%)	216 (0.72)	150 (0.52)	141 (0.49)	121 (0.46)	
Person-years	235,506	225,294	224,519	208,913	
Model 1 aHR (95% CI)	1.00 (Reference)	0.78 (0.63–0.96)	0.74 (0.60–0.92)	0.71 (0.57–0.89)	0.001
Model 2 aHR (95% CI)	1.00 (Reference)	0.77 (0.63–0.95)	0.73 (0.59–0.91)	0.71 (0.57–0.89)	0.001
Total stroke					
Events, N (%)	818 (2.73)	691 (2.41)	591 (2.07)	566 (2.10)	
Person-years	233,682	223,550	223,116	207,439	
Model 1 aHR (95% CI)	1.00 (Reference)	0.97 (0.87–1.07)	0.82 (0.74–0.92)	0.88 (0.79–0.98)	0.001
Model 2 aHR (95% CI)	1.00 (Reference)	0.96 (0.87–1.06)	0.83 (0.75–0.92)	0.88 (0.79–0.98)	0.002
Ischemic stroke					
Events, N (%)	454 (1.51)	389 (1.36)	302 (1.06)	300 (1.13)	
Person-years	234,744	224,464	223,923	208,200	
Model 1 aHR (95% CI)	1.00 (Reference)	0.99 (0.87–1.14)	0.77 (0.66–0.89)	0.87 (0.75–1.01)	0.003
Model 2 aHR (95% CI)	1.00 (Reference)	0.99 (0.86–1.13)	0.77 (0.66–0.89)	0.88 (0.76–1.01)	0.004
Hemorrhagic stroke					

Events, N (%)	150 (0.50)	127 (0.44)	130 (0.46)	139 (0.52)	
Person-years	235,713	225,400	224,604	208,838	
Model 1 aHR (95% CI)	1.00 (Reference)	0.95 (0.75–1.20)	0.97 (0.77–1.23)	1.16 (0.92–1.46)	0.235
Model 2 aHR (95% CI)	1.00 (Reference)	0.94 (0.74–1.19)	0.98 (0.78–1.24)	1.17 (0.93–1.47)	0.200

Urban green space coverage was defined as the area of parks and artificially designed green space divided by the area of residential districts. Hazard ratio calculated by Cox proportional hazards regression analysis adjustments for age, sex, income, disability, Charlson comorbidity index, body mass index, blood pressure, total cholesterol, fasting serum glucose, smoking, physical activity, and alcohol consumption. Acronyms: N, number of people; aHR, adjusted hazard ratio; CI, confidential interval.

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