Associations of residential greenness with hypertension and blood pressure in a Chinese rural population: A cross-sectional study

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Abstract

Background: Limited epidemiological literature identified the associations between residential greenness and hypertension in low/middle-income countries.

Methods: A random sampling strategy was adopted to recruit 39 259 residents, ≥ 18 years, and from 5 counties in central China. Blood pressure was measured based on the protocol of the American Heart Association. Hypertension was defined according to the 2010 Chinese guidelines for the management of hypertension. The satellite-derived Normalized Difference Vegetation Index (NDVI) and Enhanced Vegetation Index (EVI) were applied to estimate the residential greenness. Mixed logit model and mixed linear model were utilized to explore the relationships of residential greenness with hypertension and blood pressure.

Results: High residential greenness was associated with lower odds of hypertension and blood pressure levels. For instance, an interquartile range (IQR) increase in $\text{NDVI}_{500\text{m}}$ was linked with lower odds of hypertension (OR = 0.92, 95%CI 0.88 to 0.95), a decrease of -0.88 mm Hg (95%CI -1.17 to -0.58) and -0.64 mm Hg (95%CI -0.82 to -0.46) in SBP and DBP, respectively. The effect of residential greenness was more pronounced in males, smokers, and drinkers.

Conclusions: Long-term exposure to residential greenness may reduce the risk of hypertension. More prospective studies are needed to verify the hypothesis.

Introduction

Cardiovascular diseases (CVDs) drive huge deaths worldwide and hypertension is the major cause of CVDs (GBD 2018). In 2017, over 10 million global deaths were due to high systolic blood pressure (GBD 2018). Along with rapid urbanization, the hypertension prevalence was increasing, reflecting inadequate control in China (Lu et al. 2017). Apart from hereditary, behavioral, and other recognized hypertension-related factors, environmental impacts have been demonstrated in the published studies (Vienneau et al. 2017). The underlying greenspace-health mechanisms include weakening injury (eg, air pollution-buffering, noise-buffering, heat-buffering), capability recovery (eg, alleviating anxiety and depression), and improving capability (eg, offering breathing spaces, promoting social-interaction activities) (Markevych et al. 2017).

Previous studies have illustrated the associations between residential greenness and hypertension in Europe (Bijnens et al. 2017; Bloemsma et al. 2019; de Keijzer et al. 2019; Groenewegen et al. 2018; Jendrossek et al. 2017; Madhloum et al. 2019; Markevych et al. 2014), the United States (Brown et al. 2016), Australia (Dzhambov et al. 2018), and several low/middle-income countries (Jia et al. 2018; Lane et al. 2017; Moreira et al. 2020; Xiao et al. 2020; Yang et al. 2019). However, the results of those analyses remained mixed. For instance, Dzhambov et al. (2018) revealed a 36% lower hypertension prevalence per interquartile range (IQR) increase in Normalized difference vegetation index ($\text{NDVI}_{500\text{m}}$) in adults. Similar relationships were detected in the newborns (Madhloum et al. 2019) and children (Xiao et al. 2020). In

addition, null associations were identified in several studies (Bloemsma et al. 2019; Jendrossek et al. 2017; Moreira et al. 2020). For example, Jendrossek et al. (2017) concluded odds ratio (OR) = 0.889 (95%CI 0.561–1.409). Furthermore, the majority of published studies were carried out in developed countries (Jia et al. 2018; Lane et al. 2017). Convincing conclusions, undoubtedly, demands extensive investigation in various populations. Here, this study performed the population-based analyses in Chinese rural dwellers, therefore, providing new evidence in low/middle-income countries.

We hypothesized that high residential greenness may reduce the risk of hypertension. Also, the potential effect modifiers in the relationships were examined.

Methods

Study population

Rural Cohort design was described in the prior study (ChiCTR-OOC-15006699) (Liu et al. 2019b). Briefly, a random sampling was applied to select permanent dwellers, 18-79 years, and living in 5 rural zones in central China (Fig 1 and 2). Overall, 39259 participated in the study. Subjects without outcome (eg, SBP/DBP) were excluded in the final analyses. The signed informed consent was received before the survey. This study was approved by the Zhengzhou University review board.

Outcome

SBP/DBP was measured thrice utilizing OMRON HEM-770A according to the American Heart Association guideline (Pickering et al. 2005). The protocol was published previously (Li et al. 2020). Prior to measurement, smoking, drinking, and physical exercise were forbidden within half an hour. In addition, talking was forbidden during the measurement. Hypertension, by definition of 2010 Chinese guideline (Wang et al. 2018), SBP $\geq$ 140 mm Hg, DBP $\geq$ 90 mm Hg, diagnosis history of hypertension, and use of the antihypertensive drug.

Greenness exposure

The NDVI and EVI databases were downloaded from the National Aeronautics and Space Administration to estimate the residential greenness for each participant. The assessment was described elsewhere (Xie et al. 2020). The two vegetation indexes could effectively characterize vegetation states and processes. NDVI has been used widely for environmental applications (Jia et al. 2018). Compared with NDVI, EVI could minimize canopy-soil variations and improved sensitivity over dense vegetation conditions (Qiu et al. 2018). Long-term exposure to greenness was defined as the 3-year average of NDVI/EVI prior to the survey.

Covariates

Demographics included age, sex, region (Xinxiang, Suiping, Yuzhou, Yima, and Tongxu), marriage (no, yes), education (low, medium, high), income/month (yuan) ($\leq$ 500, 500~, 1000). Behavioral factors

included smoking, drinking, fat-rich diet, and exercise. Fat-rich diet (Yang et al. 2018) and exercise (Craig et al. 2003) information were obtained from a standard questionnaire. Health status included family history of hypertension and body mass index (BMI). A spatiotemporal model was performed to assess the exposure to fine particulate matter (PM_{2.5}) at a 0.1° × 0.1° spatial resolution (Chen et al. 2018). The accuracy of the method was verified elsewhere (10-fold cross-validation R² = 86%) (Liu et al. 2019a).

Statistical analysis

Mixed logit model and mixed linear model were employed to explore the associations between residential greenness and hypertension and blood pressure. Long-term exposure to greenness was utilized in the main model. The models were widely used in recent studies (Xiao et al. 2020; Yang et al. 2019). Given the possible influence of regional clustering, the region was controlled as a random effect in the analyses (Xie et al. 2020). Adjustment of fixed effects was as follows: (1) Crude model: non; (2) Adjusted model: adjusted for age, sex, marriage, education, income/month, smoking, drinking, fat-rich diet, exercise, family history of hypertension, BMI, and PM_{2.5} (Dzhambov et al. 2018; Lane et al. 2017). To test effect modifications of behavioral factors in the greenness-hypertension/blood pressure associations, the interaction analysis was performed by putting the interaction items in the adjusted model.

Considering the possible mediation in the greenness-hypertension/blood pressure pathways (eg, air pollution, exercise) (de Keijzer et al. 2019; Xie et al. 2020), serial mediation analyses were carried out. To verify the reliability of conclusions, sensitivity analyses were conducted: (1) The average of 1-year and 2-year NDVI_{500m}/EVI_{500m} prior to the survey was employed to test long-term impacts of greenness on hypertension and blood pressure; (2) The greenness-hypertension/blood pressure relationships were investigated utilizing different buffers (NDVI_{1000m}/EVI_{1000m}, NDVI_{3000m}/EVI_{3000m}); (3) To eliminate the causal effect of hypertension on blood pressure, subjects with hypertension and taking the antihypertensive drug were excluded.

Analyses were conducted in R 4.0.2 loading “lme4” and “mediation” packages.

Results

This analysis involved 39 094 participants (60.6% females, n = 23 677) (Table 1). The characteristics of participants by region was presented in Table S1. Among 39 094 participants, 19.1% (n = 7458) were smokers, 18.0% (n = 7053) were drinkers, 19.1% (n = 7461) had a fat-rich diet, and 32.3% (n = 12 614) reported a low level of physical exercise. The 3-year average NDVI_{500m} and EVI_{500m} were 0.4785 and 0.3380 units (Table S2). A total of 12 763 hypertensive patients were identified (prevalence = 32.6%), 61.3% were self-reported, 38.7% were diagnosed by trained physicians.

Table 1
Characteristics of participants.

Variables		Hypertension	Non-hypertension	All
N		12763	26331	39094
Age (mean $\pm$ SD)		60.37 $\pm$ 10.09	53.26 $\pm$ 12.43	55.58 $\pm$ 12.18
Sex (n, %)	Male	5094 (39.9)	10323 (39.2)	15417 (39.4)
	Female	7669 (60.1)	16008 (60.8)	23677 (60.6)
Education (n, %)	Low	6793 (53.2)	10689 (40.6)	17482 (44.7)
	Medium	4395 (34.4)	11197 (42.5)	15592 (39.9)
	High	1575 (12.3)	4445 (16.9)	6020 (15.4)
Married (n, %)		11121 (87.1)	23984 (91.1)	35105 (89.8)
Income/month (n, %)	$\leq$ 500 yuan	5045 (39.5)	8899 (33.8)	13944 (35.7)
	500~	4200 (32.9)	8650 (32.9)	12850 (32.9)
	$\geq$ 1000 yuan	3518 (27.6)	8782 (33.4)	12300 (31.4)
Smoking (n, %)	Never	9353 (73.3)	19109 (72.6)	28462 (72.8)
	Former	1333 (10.4)	1841 (7.0)	1819 (4.7)
	Current	2077 (16.3)	5381 (20.4)	7458 (19.1)
Drinking (n, %)	Never	9765 (76.5)	20457 (77.7)	30222 (77.3)
	Former	709 (5.6)	1110 (4.2)	1819 (4.7)
	Current	2289 (17.9)	4764 (18.1)	7053 (18.0)
Exercise (n, %)	Low	4783 (37.5)	7831 (29.7)	12614 (32.3)
	Medium	4377 (34.3)	10391 (39.5)	14768 (37.8)
	High	3603 (28.2)	8109 (30.8)	11712 (29.9)
Fat-rich diet (n, %)		2009 (15.7)	5452 (20.7)	7461 (19.1)
Family history of hypertension (n, %)		3515 (27.5)	4049 (15.4)	7564 (19.3)
Body mass index (kg/m ² , mean $\pm$ SD)		26.03 $\pm$ 3.65	24.25 $\pm$ 3.36	24.83 $\pm$ 3.56
PM _{2.5} (μ g/m ³ , mean $\pm$ SD)		73.86 $\pm$ 2.43	73.21 $\pm$ 2.61	73.42 $\pm$ 2.57

Abbreviations: SD, standard deviation; PM_{2.5}, fine particulate matter.

High residential greenness was related to 8%-11% lower hypertension prevalence, 0.79–1.18 mmHg decreased SBP, and 0.64–1.11 mm Hg decreased DBP (Fig. 3). For example, each IQR (0.08 units) increase in $\text{NDVI}_{500\text{m}}$ was related to 8% lower odds of hypertension, a reduction of 0.88 mmHg in SBP, and 0.64 mmHg in DBP in the adjusted model. Interaction analysis concluded that the effect of residential greenness on hypertension/blood pressure was more pronounced in males, smokers, and drinkers ($P_{\text{interaction}} < 0.05$) (Fig. 4). For instance, high $\text{NDVI}_{500\text{m}}$ was related to 13% lower odds of hypertension among males, whereas 5% among females ($P_{\text{interaction}} = 0.005$). In addition, a decrease of 1.30 mm Hg in SBP among males, compared with 0.63 mmHg among females ($P_{\text{interaction}} = 0.002$).

$\text{PM}_{2.5}$, exercise, and BMI partially mediated the relationships between residential greenness and hypertension and blood pressure (Table S3). The proportion of mediation for $\text{PM}_{2.5}$, exercise, and BMI varied between 3.7–21.6%, 0.7–4.4%, and 23.6–36.7%, respectively. Compared with main analyses, using the 1-year/2-year average $\text{NDVI}_{500\text{m}}/\text{EVI}_{500\text{m}}$ and $\text{NDVI}_{1000\text{m}}/\text{EVI}_{1000\text{m}}$ showed similar results (Fig S1). The enhanced association was detected using $\text{NDVI}_{3000\text{m}}/\text{EVI}_{3000\text{m}}$. For example, each IQR increase in $\text{NDVI}_{3000\text{m}}$ was related to 19% lower odds of hypertension. Changes in SBP/DBP remained similar when participants taking the antihypertensive drug were excluded. After excluding hypertensive patients, the relationships were attenuated but remained significant. Each IQR increase in $\text{NDVI}_{500\text{m}}$ was linked to 0.40 mmHg lower SBP and 0.32 mm Hg lower DBP.

Discussion

The studies of the greenness-hypertension pathways are still in the initial stage and lack of systematic studies in low/middle-income countries. We found that elevated residential greenness was associated with 8%-11% decreased hypertension prevalence, 0.79–1.18 mmHg lower SBP, and 0.64–1.11 mm Hg lower DBP. In addition, sex, smoking, and drinking could further modify the relationships. Given increasing environmental pollution accompanied by the accelerated urbanization process and high hypertension prevalence in China as well as other low/middle-income countries, our findings may be particularly important for public health.

In the present study, each IQR increment in $\text{NDVI}_{500\text{m}}$ was related to 8% lower odds of hypertension. Similar conclusions were drawn not only in adults (Brown et al. 2016; de Keijzer et al. 2019; Dzhambov et al. 2018; Jia et al. 2018; Vienneau et al. 2017; Yang et al. 2019) but also in children (Xiao et al. 2020). For instance, Brown et al. (2016) indicated 13% lower odds of hypertension among elderly Americans (≥ 65 years) attributed to high residential greenness. Additionally, each 0.1-unit increment in $\text{NDVI}_{500\text{m}}$ was related to 24% lower hypertension prevalence in Chinese children (Xiao et al. 2020). However, Jendrossek et al. (2017) revealed a null association among German adults (OR = 0.889, 95%CI 0.561–1.409). A meta-analysis of 4 studies concluded no significant greenness-hypertension association (OR = 0.99, 95%CI 0.81–1.20) (Twohig-Bennett and Jones 2018). Limited evidence from low/middle-income countries, therefore, a comprehensive greenness-hypertension pathway remained deeply studied. In addition, the meta-analysis identifying those relationships need to be updated.

High residential greenness was linked with lower SBP/DBP in the current analysis. In line with our result, Lane et al. (2017) found 4.3 mmHg lower SBP and 1.2 mmHg lower DBP per IQR increment in $NDVI_{250m}$ among Indian adults. However, inconsistent results existed in several previous studies (Bijnens et al. 2017; Bloemsma et al. 2019; Dzhambov et al. 2018; Madhloum et al. 2019; Markevych et al. 2014; Xiao et al. 2020; Yang et al. 2019). For instance, the significant $NDVI_{500m}$ -SBP association was observed, whereas the null $NDVI_{500m}$ -DBP association in Chinese adults (Yang et al. 2019). In addition, Madhloum et al. (2019) drew the opposite conclusion indicating no significant greenness-SBP relationship, whereas the significant greenness-DBP relationship in newborns. No significant association was found between greenness and SBP/DBP in adolescents (Bloemsma et al. 2019). The study population mentioned above (eg, adult, newborn, children) have different characteristics that may modify the effect of greenness. Besides, differences in study design, greenness assessment may explain the inconsistency. Thus, the greenness-SBP/DBP pathways remained unclear.

The mechanism by which long-term exposure to residential greenness reduces the risk of hypertension could be explained by immunological pathways (Rook 2013). Specifically, people residing in green space are exposed to more diverse microbes beneficial to the host immune system (improving immune regulation) and less noise and air pollution (reducing inflammatory response), are more likely to increase physical activity (strengthening immune and nervous system), promote the exchange of microbiota (increasing social interactions), and promote metabolism (sunlight helping in the synthesis of vitamin D). Also, high residential greenness ease tension and depression by increasing social interactions (Banay et al. 2019).

Interaction analysis showed that males, smokers, and drinkers tended to be more susceptible to the effect of greenness. Whether sex modifies the greenness-hypertension relationship remained unclear in previous studies (Dzhambov et al. 2018; Jia et al. 2018; Xiao et al. 2020; Yang et al. 2019). For example, Jia et al. (2018) reported $OR_{male} = 0.14$ (95%CI 0.11–0.48) and $OR_{female} = 0.45$ (95%CI 0.36–0.63) and it was consistent with our finding. However, Yang et al. (2019) found a null association in males, whereas the a significant association in females. In addition, Xiao et al. (2020) observed no significant sex interaction in $NDVI_{500m}$ -hypertension relationship ($OR_{male} = 0.81$ vs. $OR_{female} = 0.72$, $P_{interaction} = 0.279$). Smoking and drinking could trigger inflammatory response, oxidative stress, and metabolic disorders, which further affect systemic vascular resistance (Joseph et al. 2017). Long-term exposure to greenness could provide diverse microbes, some of which are important inducers of the immunoregulatory pathways, and activation of the immune regulatory system consequently reduced chronic inflammation (Rook 2013). Thus, the effect of greenness on hypertension and blood pressure was more pronounced in smokers and drinkers.

Several limitations existed in the present study. First, as an inherent drawback of cross-sectional design, causal associations should be treated with caution. Second, demographics, behavioral factors, and health status were collected using the questionnaire, which may introduce recall bias. Third, some

potential confounders including noise, the walkability of the community, and indoor exposure to greenness were not adjusted because of unavailability (Dzhambov et al. 2018; Xiao et al. 2020).

Conclusion

Long-term exposure to residential greenness may reduce the risk of hypertension. Furthermore, males, smokers, and drinkers were more susceptible to the effect of greenness. Given the limitations of design, prospective studies are warranted in future analysis.

Declarations

Acknowledgments

We acknowledge the participants in the study.

Authors' contributions

JJ: analysis, visualization, writing manuscript; GC: methodology, interpretation; BL: interpretation; NL: analysis, data curation; FL: validation, data curation; YL: methodology, supervision; YG: validation, funding acquisition; SL: methodology, funding acquisition; LC: visualization, methodology; HX: editing, funding acquisition. All authors read and approved the final manuscript.

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Ethics approval and consent to participate

This study was approved by the Zhengzhou University review board.

Consent for publication

Not applicable

Data availability

Upon reasonable request, data are available from the corresponding author.

Competing interests

No competing interests

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Figures

Figure 1

The flowchart of participant recruitment

Figure 2

Locations of study regions in the study. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

Figure 3

The relationships between residential greenness and hypertension and blood pressure. Abbreviations: NDVI, normalized difference vegetation index; EVI, enhanced vegetation index; SBP, systolic blood pressure; DBP, diastolic blood pressure. Note: Crude model: no adjustment; Adjusted model: Adjusted for age, sex, marriage, education, income, smoking, drinking, fat-rich diet, exercise, family history of hypertension, BMI, and PM2.5.

Figure 4

Interaction analyses in the relationships between residential greenness and hypertension and blood pressure. Abbreviations: NDVI, normalized difference vegetation index; EVI, enhanced vegetation index. Note: Adjusted for age, sex, marriage, education, income, smoking, drinking, fat-rich diet, exercise, family history of hypertension, BMI, and PM2.5.

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