HUMAN BIOLOGY
2024, VOL. 94, ISSUE 3
ORIGINAL ARTICLE

OPEN ACCESS

# The Relationship Between Long-Term Exposure to Environmental NO2 and HDL Levels Among Middle-Aged and Older Adults in China

***Lu Fang[1], Shuju Zhao [2], Peng Liang[1]***

## ABSTRACT

**Background:** In recent years, an increasing number of studies have confirmed that air pollution mixtures can lead to abnormal levels of lipid proteins in the body. With the continuous deepening of research, the specific effects of different components in air pollution mixtures on human health have gradually begun to be explored. Nitrogen dioxide (NO2), as an essential component of air pollutants, hurts human health. Normal levels of high-density lipoprotein (HDL) play a crucial role in preventing cardiovascular diseases. However, the effect of environmental NO2 on HDL levels has yet to be further studied. Our study aims to explore the potential association between environmental NO2 exposure and HDL levels in middle-aged and elderly populations aged 45 and above in China

**Methods:** Our research subjects are the third-wave China Health and Retirement Longitudinal Study (CHARLS) participants. This cross-sectional study analyzed the personal data of 12519 participants aged 45 and above with venous blood samples. The participants' high-quality and high-resolution NO2 exposure concentration data were obtained from the Chinese Air Pollutants (CHAP) dataset, and the HDL levels were obtained from the analysis results of venous blood samples. Multiple linear regression analysis, supplemented by subgroup analysis, was used to explore the correlation between NO2 exposure concentration and HDL levels.

**Results:** This cross-sectional study found a negative correlation between long-term exposure to air NO2 and HDL levels. The observed correlation between air NO2 and HDL levels indicates that middle-aged and older adults living in areas with high NO2 concentrations exhibit a decrease in HDL levels (Beta: -0.132; 95% CI: (-0.153, -0.111); P<0.0001). This association still exists after considering various potential confounding factors (Beta=-0.103, 95% CI: -0.124, -0.083, p<0.0001).

**Conclusion:** Our research results show a significant negative correlation between long-term exposure to high concentrations of NO2 and HDL levels in the middle-aged and elderly population in China.

## INTRODUCTION

Air pollution is a complex mixture of particles, gases, and chemicals, considered the most significant environmental factor causing global life loss and generating over 4.2 million deaths annually WHO et al. (2021). However, hundreds of millions of people worldwide are continuously affected by high-level air pollution Li JP et al. (2019), especially in developing countries such as China and India Murray CJL et al. (2020). Based on this, the World Health Organization has identified air pollution as the environmental problem with the most significant impact on health, which may pose a severe threat to global public health in the future. High-density lipoprotein (HDL) has anti-inflammatory and antioxidant properties Soran et al. (2015), and normal levels of HDL play a core role in protecting cardiovascular system function and preventing cardiovascular events Rosenson RS et al. (2016). Many studies have found that exposure to air pollution may increase the incidence rate and mortality of cardiovascular diseases by reducing the level of HDL Mao SY et al. (2020), Wu XM et al. (2019), Zhang WL et al. (2022), Gaio V et al. (2019), Kim et al. (2019), McGuinn LA et al. (2019), Kim KN et al. (2022), especially for the elderly Brook RD et al. (2010). The unclear specific effects of different components in air pollution mixtures on the body hinder the improvement of air pollution prevention and control strategies Zhang WL et al. (2022); Therefore, in recent years, many studies have begun to evaluate the effects of different components of air pollutants (such as PM10, PM2.5, and NO2) on HDL levels Ossoli A et al. (2022). Nitrogen dioxide (NO2), a standard air pollutant, is formed by the combustion of fossil fuels in vehicle sources, power

[1]Day Surgery Center, General Practice Medical Center, West China Hospital, Sichuan University, Chengdu, China
[2]Shandong Daizhuang Hospital, Jining, China

**Correspondence to:** Peng Liang, Day Surgery Center, General Practice Medical Center, West China Hospital, Sichuan University, Chengdu, China.
E-mail: liangpeng@wchscu.cn.

**Keywords:** HDL; NO2; air pollution; China; middle-aged and older adults

plants, and wildfires Chen H et al. (2021). Its harmful effects may be more potent than PM2.5 and PM10 Pan MN et al. (2023), and increasing epidemiological evidence suggests that exposure to NO2 can cause varying degrees of harm to human health. Multiple studies have found that short-term and long-term exposure to NO2 increases the risk of neurodegenerative diseases, including cognitive impairment and dementia in the elderly Tzivian L et al. (2015), Carey IM et al. (2018), Chen H et al. (2017). Meanwhile, long-term exposure to high concentrations of NO2 increases the risk of dyslipidemia in young people Kim JS et al. (2019), leading to an increase in triglycerides Patterson WB et al. (2023) and serum total cholesterol levels in the body Gui ZH et al. (2020). However, current research on the correlation between air NO2 exposure and HDL levels shows differences and uncertainties Li JP et al. (2019), Yang BY et al. (2018), Wang MZ et al. (2018). In addition, most recent research focuses on the population of high-income countries, and there needs to be more research evidence on the population of middle and low-income countries with more severe air pollution Murray CJL et al. (2020), Yusuf S et al. (2020). Previous studies have shown that as age increases, the body's ability to synthesize, degrade, and transport cholesterol decreases, and lipid levels also undergo adverse changes Johnson AA et al. (2019); therefore, middle-aged and elderly populations exhibit a higher susceptibility to air pollution Yang BY et al. (2018), Wang MZ et al. (2018), Meanwhile, given the continuously increasing dietary habits and prevalence of dyslipidemia among the Chinese population Pan L et al.(2016), Peters SAE et al.(2019), it is necessary to study the impact of air NO2 exposure on HDL indicators in the middle-aged and elderly population in China. It is of great significance to maintain the normal HDL levels of the middle-aged and elderly population in China, promote cardiovascular health, and reduce the social, economic, and medical burden.

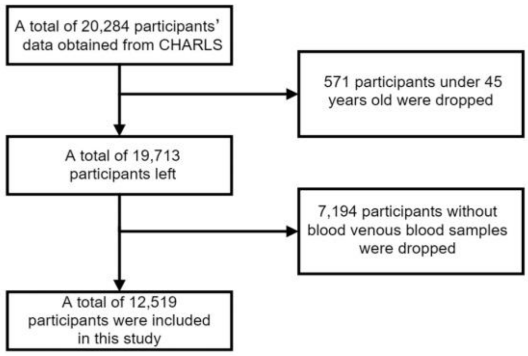
## METHODS

### Data Resource

The data of this article is from the third wave of CHARLS; CHARLS (https://g2aging.org/) is a nationwide cohort study conducted by the National Development Research Institute of Peking University, using a multi-stage stratified probability sampling method to sample the middle-aged and elderly population of 150 municipalities directly under the central government in 28 provinces, municipalities, and autonomous regions across the country. This study started investigating and collecting data from 2011 to 2012 and has since collected data every two years. It provides longitudinal data on demographic indicators, family conditions, biomedical indicators, health status, and body functions of the middle-aged and elderly population in China. CHARLS has been approved by the Ethics Committee of Peking University School of Medicine, and the detailed investigation design plan has been described elsewhere Zhao YH et al. (2014).

The third wave of the CHARLS survey had a total of 20284 participants, excluding 571 participants under the age of 45 and further excluding 7194 participants who did not undergo venous blood collection; this study ultimately included 12519 participants. For details on excluding participants, please refer to Figure 1.

**Figure 1:** Flowchart of the participants selection




### Definition of Environmental NO2 Exposure Concentration and HDL Level

The NO2 exposure concentration in the participant's environment was obtained from the China Air Pollutants (CHAP) dataset Wei J et al. (2021), which uses multi-source satellite remote sensing and artificial intelligence technology combined with rich ground observation data, satellite remote sensing products, atmospheric reanalysis, and model simulation to eliminate the spatiotemporal heterogeneity of air pollution. High-quality NO2 data with a 1-kilometer resolution in China from 2000 to 2018 were obtained for recording. This study considers the participants' privacy issues in their residences. The NO2 concentration in the city-level environment where the participants reside is taken as the personal level data of the participants, and the average value from the beginning of the study (2011) to the end of the study (2015) is taken as the exposure level of NO2 in the participants' environment. The collected blood samples are analyzed for whole blood cell count (CBC) at the local health centre and then sent to the research headquarters for HDL measurement Chen XX et al. (2019).

### Covariates

To eliminate any possible confounding variables, this study analyzed specific parameters that have been previously proven to affect HDL levels. Quantify age in years. BMI was calculated by dividing the weight in kilograms by the square of the height in meters. According to different levels of education, it is divided into two categories: secondary education and below and higher education. Residential locations are divided into rural and urban areas. Marital status is divided into two categories: married or with a partner, as well as separated, divorced, widowed or unmarried; Divided into different subgroups based on the subject's smoking and alcohol consumption; At the same time, participants were asked whether they had been diagnosed as the following diseases by doctors in the past: such as hypertension, diabetes, respiratory diseases, heart diseases, stroke, psychological diseases, arthritis, dyslipidemia, liver diseases, kidney diseases, digestive system diseases, etc. Missing covariates are inputted using multivariate input techniques that rely on predictive mean-matching methods.

**Statistical Analysis**

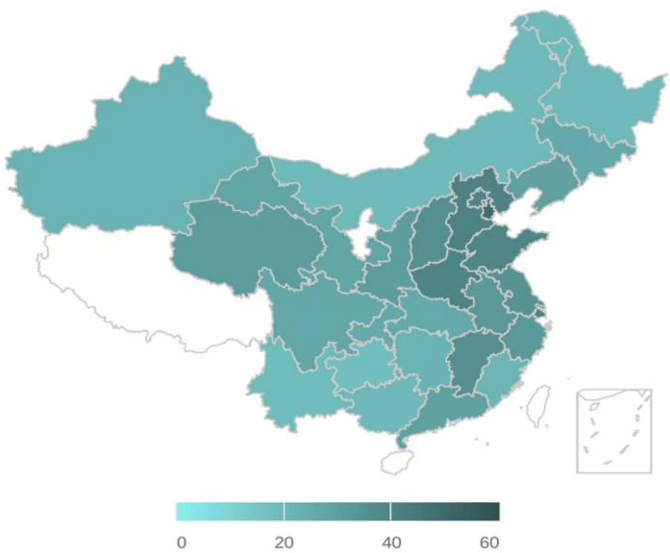
Standard deviation and mean represent continuous variables in baseline features, while ratios and percentages indicate categorical variables. Kruskal Wallis test is used to determine the p-value of constant variables; Classification data analysis adopts the chi-square test. Fisher's exact test is used when the theoretical number is less than 10 Ma K et al. (2024). Environmental NO2 exposure concentration and HDL level were treated as continuous variables. We stratified the baseline data by gender to examine potential differences among the middle-aged and elderly. Multiple linear regression analysis was used to study the relationship between environmental NO2 exposure concentration and high-density lipoprotein levels. To reduce the impact of confounding factors on the research results, models I-IV were set up to adjust for different covariates. Model I only adjusted for age, which is divided into four age groups based on the age of the subjects: 50 years old, 60 years old, 70 years old, and over 70 years old; Model II adjusted for the age, gender, education level, marital status, and place of residence of the subjects; Model III added variables such as smoking and alcohol consumption, BMI, etc. to Model II for additional variable adjustments; Model IV adds adjustments for previously diagnosed disease variables based on Model III. Using interaction analysis and covariate stratification to examine the heterogeneity of the association between environmental NO2 exposure concentration and HDL levels. Use stratified linear regression analysis for subgroup analysis and use a logarithmic likelihood ratio test to determine the p-value of interactions, which involves comparing models with and without covariate interactions. All statistical results of this study are considered statistically significant at a significance level of 0.05. All analyses were conducted using version R 4.2.2.

## RESULTS

**Baseline characteristics of investigators and the average level of NO2 concentration at the urban level in China**

A total of 12519 participants were included in this study, and the baseline characteristics of the participants are detailed in Table 1. Analysis shows that female participants have higher HDL levels than male participants (52.30 ± 10.80 mg/dl vs 49.96 ± 12.38 mg/dl, $p<0.001$). Meanwhile, the average age of female participants was lower than that of male participants (60.16 ± 9.74 vs 61.33 ± 9.73, $p<0.001$). There were statistically significant differences ($P<0.05$) between participants of different genders in terms of place of BMI, residence, education level, marital status, alcohol consumption, smoking, and comorbidities. The NO2 concentration at the city level where the participants are located is shown in Figure 2.

**Figure 2:** The annual average of NO2 concentration of participants living provinces.



OPEN ACCESS

**Table 1:** Baselines characteristics of the participants enrolled

| | | Gender | | |
|---|---|---|---|---|
| | | **male** | **female** | **P** |
| | | n=5889 | n=6630 | |
| hdl (mean (SD)) | mg/dl | 49.96 (12.38) | 52.30 (10.80) | <0.001 |
| NO2 (mean (SD)) | | 30.14 (9.69) | 30.32 (9.81) | 0.287 |
| age (mean (SD) | year | 61.33 (9.73) | 60.16 (9.74) | <0.001 |
| age_class (%) | <50 | 744 (12.63) | 989 (14.92) | <0.001 |
| | <60 | 1840 (31.24) | 2283 (34.43) | 1 |
| | <70 | 2095 (35.57) | 2194 (33.09) | 1 |
| | >=70 | 1210 (20.55) | 1164 (17.56) | 1 |
| BMI (mean (SD)) | | 23.84 (11.44) | 25.04 (17.62) | <0.001 |
| residence (%) | urban | 1163 (22.25) | 1098 (18.51) | <0.001 |
| | rural | 4064 (77.75) | 4834 (81.49) | 1 |
| education_level (%) | Less than lower secondary | 5761 (97.86) | 6571 (99.14) | <0.001 |
| | tertiary | 126 (2.14) | 57 (0.86) | 1 |
| marital_status (%) | married or partnered | 5293 (89.88) | 5569 (84.00) | <0.001 |
| | separated divorced widowed or never married | 596 (10.12) | 1061 (16.00) | 1 |
| drinking_feq (%) | none | 2473 (42.14) | 5612 (84.95) | <0.001 |
| | less than once per day | 1920 (32.72) | 834 (12.62) | 1 |
| | once per day | 800 (13.63) | 108 (1.63) | 1 |
| | twice per day | 490 (8.35) | 45 (0.68) | 1 |
| | more than twice per day | 185 (3.15) | 7 (0.11) | 1 |
| smoking_feq (%) | none | 2750 (47.23) | 6285 (95.14) | <0.001 |
| | <=4 | 293 (5.03) | 58 (0.88) | 1 |
| | <=10 | 763 (13.11) | 139 (2.10) | 1 |
| | >10 | 2016 (34.63) | 124 (1.88) | 1 |
| hypertension (%) | no | 3291 (65.56) | 3664 (63.36) | 0.018 |
| | yes | 1729 (34.44) | 2119 (36.64) | 1 |
| diabetes (%) | no | 4543 (90.86) | 5069 (88.34) | <0.001 |
| | yes | 457 (9.14) | 669 (11.66) | 1 |
| lungdis (%) | no | 4162 (82.63) | 5107 (88.23) | <0.001 |
| | yes | 875 (17.37) | 681 (11.77) | 1 |
| heartdis (%) | no | 4195 (83.58) | 4532 (78.80) | <0.001 |
| | yes | 824 (16.42) | 1219 (21.20) | 1 |
| stroke (%) | no | 4813 (95.51) | 5621 (96.88) | <0.001 |
| | yes | 226 (4.49) | 181 (3.12) | 1 |
| psydis (%) | no | 4958 (98.28) | 5637 (97.39) | 0.002 |
| | yes | 87 (1.72) | 151 (2.61) | 1 |
| arthritis (%) | no | 3072 (60.76) | 2993 (51.93) | <0.001 |
| | yes | 1984 (39.24) | 2771 (48.07) | 1 |
| dyslipidemia (%) | no | 3974 (80.85) | 4428 (78.80) | 0.01 |
| | yes | 941 (19.15) | 1191 (21.20) | 1 |
| liverdis (%) | no | 4638 (92.48) | 5411 (93.99) | 0.002 |
| | yes | 377 (7.52) | 346 (6.01) | 1 |
| kidneydis (%) | no | 4455 (88.69) | 5260 (91.27) | <0.001 |
| | yes | 568 (11.31) | 503 (8.73) | 1 |
| digestdis (%) | no | 3636 (71.97) | 3792 (65.50) | <0.001 |
| | yes | 1416 (28.03) | 1997 (34.50) | 1 |
| asthma (%) | no | 4674 (92.59) | 5484 (94.83) | <0.001 |
| | yes | 374 (7.41) | 299 (5.17) | 1 |

Baselines characteristics of the participants enrolled (SD: standard deviation, SD for continuous variables: P value was calculated by Kruskal Wallis rank-sum test, Number (%) for categorical variables: P value was calculated by chi-square test, HDL: high-density lipoprotein cholesterol)

OPEN ACCESS

### The relationship between environmental NO2 concentration and high-density lipoprotein HDL level

Table 2 shows the multivariate regression analysis results of the relationship between NO2 concentration and HDL level in the participant's environment. In the rough model, the correlation between environmental NO2 concentration and HDL level indicates that older adults with higher environmental NO2 concentration levels have lower HDL levels (Beta: -0.132; 95% CI: (-0.153, -0.111); P<0.0001). After controlling for age, the Beta value of Model I is -0.132 (95% CI: -0.153, -0.112; P<0.0001). Even after considering several possible confounding factors, both Model II (Beta: -0.136; 95% CI: -0.156, -0.115; p<0.0001) and Model III (Beta: -0.124; 95% CI: -0.144, -0.104, p<0.0001) remained consistent. Model IV (Beta=-0.103, 95% CI: -0.124, -0.083, p<0.0001) adjusted for all possible confounding variables, and the analysis results remained statistically significant. According to Model I in multivariate regression analysis, age may affect the correlation between environmental NO2 concentration and HDL levels. From Model III, smoking, alcohol consumption, and BMI may contribute to this association. The research results of Model IV indicate that the presence of comorbidities significantly affects the overall correlation.

**Table 2:** Multivariate regression model of the relationship between NO2 and the level of HDL

| Supplement 2 Multivariate regression model of the relationship between NO2 and the level of HDL | | |
|---|---|---|
| **Exposure** | **Crude model** | |
| | **Beta (95%CI)** | **P-value** |
| Crude model | -0.132 ( -0.153 , -0.111 ) | <0.0001 |
| Model I | -0.132 ( -0.153 , -0.112 ) | <0.0001 |
| Model II | -0.136 ( -0.156 , -0.115 ) | <0.0001 |
| Model III | -0.124 ( -0.144 , -0.104 ) | <0.0001 |
| Model IV | -0.103 ( -0.124 , -0.083 ) | <0.0001 |
| Crude model adjust for none ； | | |
| | | |
| Model I adjust for: age | | |
| | | |
| Model II adjust for: age; gender; education level; marital status; residence | | |
| Model III adjust for:age; gender; education level; marital status; residence; smoking condition; drinking condition; BMI | | |
| Model IV adjust for: age; gender; education level; marital status; residence; smoking condition; drinking condition; BMI; hypertension; diabetes; lung diseases; heart diseases; stroke; psych problems; arthritis; dyslipidemia; liver diseases; kidney diseases; digest diseases; asthma | | |

Multivariate liner regression was used to identify the association between ambient NO2 and HDL level.; CI: confidence interval; BMI: body mass index.

### Subgroup Analysis

The results in Figure 2 indicate a significant correlation between environmental NO2 concentration and HDL levels across different age groups and genders. In addition, this correlation also remains consistent across other population groups, such as those living in rural areas, those who do not smoke or smoke more than four cigarettes per day, and those who do not drink alcohol or drink less than once a day. The results of the interaction test showed that age, gender, place of residence, smoking and drinking had a significant impact, and the p-value of the interaction was statistically significant.

## DISCUSSION

The ageing problem in China is becoming increasingly severe, and the number of older adults aged 60 and above will increase significantly by 2031 Ye X et al. (2023). HDL, as a beneficial lipid index in the body, protects vascular wall function and prevents cardiovascular accidents. Therefore, normal HDL levels have crucial clinical significance. Rosenson RS et al. (2016) This study is the first to explore the relationship between air NO2 exposure and HDL levels in middle-aged and older adults aged 45 and above in China. Our cross-sectional study found that long-term exposure to environmental NO2 is negatively correlated with HDL levels, and middle-aged and older adults with higher levels of ecological NO2 exposure have lower HDL levels. Our study, based on previous research findings, found that this association remained consistent even after considering multiple possible confounding factors in the past. Multiple studies have shown that exposure to different environmental air pollutants can hurt lipid metabolism in the general population Mao SY et al. (2020), Kim KN et al. (2022), Gui ZH et al. (2020), Mao SY et al. (2020). Exposure to air pollutants has a more significant adverse effect on the elderly, obese, and people with previous cardiovascular disease or diabetes de Bont J et al. (2022). But so far, most studies have focused on the adverse effects of PM2.5 and PM10 components in air pollution on blood lipid abnormalities Mao SY et al. (2020), with only a few studies on the effects of NO2, an air pollution component, on the HDL levels. In the study of Spanish adults Valdés S et al. (2024) and Danish adults Roswall N et al. (2023), a significant negative correlation was found between exposure to NO2 and HDL levels, and our findings are consistent with previous studies. Therefore, because of previous studies that confirmed the critical role of HDL in preventing the development of atherosclerosis, new insights were provided for studying the vital mechanism of different air pollutants promoting cardiovascular diseases Li JP et al. (2019) However, the exact mechanism of air pollution affecting lipid levels has yet to be entirely determined. Some studies suggest that air pollution can induce systemic and oxidative stress Chen ST et al. (2013), Chen T et al. (2013), Li RS et al. (2013), leading to a decrease in lipid output capacity. Zhang YZ et al. (2003). Another part of the research suggests that air pollution can lead to abnormal DNA methylation Li HC et al. (2018), altering specific genes related to lipid metabolism Bind MA et al. (2014); As a free radical, NO2 can have an impact on health through oxidative stress and inflammatory reactions WHO et al. (2010). Previous studies have found that PM components in air pollution can cause local oxidative stress, and the presence of NO2 can enhance oxidative stress Mudway IS et al. (2000). This may be one of the mechanisms by which NO2 affects the body's HDL levels.

Although the participants in this study were screened nationwide, there are some inevitable

**Limitations:**

This study is cross-sectional, and the causal relationship between air NO2 exposure concentration and HDL has yet to be accurately determined. The exclusion of various confounding factors in the study was based on the patient's self-report and did not yield objective examination results and diagnosis. Considering the privacy issues of the respondents, only city-level NO2 data can be obtained as a representative of personal-level data, which may have inevitable errors. However, we expect more prospective and intervention studies in the future to provide more comprehensive explanations.

## CONCLUSIONS

Our research findings indicate a significant correlation between long-term exposure to air NO2 and HDL levels, and after considering potential confounding variables, long-term NO2 exposure can also lead to a decrease in HDL levels in middle-aged and elderly population. Therefore, middle-aged and elderly population should pay more attention to taking protective measures to reduce NO2 exposure. At the same time, considering the development trend of the ageing population in China, the results of this study also provide a reference for further research on the relationship between different components of environmental air pollution and HDL levels and provide a scientific basis for relevant departments to formulate policies, to reduce the burden of cardiovascular disease and protect the health of middle-aged and older adults through feasible and achievable targeted intervention measures. We look forward to more research in the future to elucidate this correlation and potential mechanisms of action.

## DECLARATIONS

### Acknowledgments

The authors thank the National Development Research Institute of Peking University and the China Social Science Survey Center of Peking University for providing CHARLS data, participants, and researchers. At the same time, we also want to thank the Chinese Air Pollutants (CHAP) researchers.

### Author Contributions

Conception and design FL. Data acquisition and analysis FL ZS. Drafting of the work LP. Revised and reviewed the article FL LP. All authors approved the final version of the manuscript.

### Funding Statement

No funding

### Data Availability

Publicly available datasets analyzed in this study can be found on the CHARLS website (https://charls.pku.edu.cn/) and the CHAP website (https://weijing-rs.github.io/index.html).

### Ethics approval and consent to participate

All data used in this study were from the public domain.

OPEN ACCESS

**Consent for publication**

Not applicable.

**Conflict of Interest**

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

**Competing interests**

The authors declare that they have no competing interests.

**REFERENCES**

1.WHO Guidelines Approved by the Guidelines Review Committee. 2021.In: WHO global air quality guidelines: Particulate matter (PM(25) and PM(10)), ozone, nitrogen dioxide, sulfur dioxide and carbon monoxide. edn. Geneva: World Health Organization © World Health Organization.

2.Li JP, Zhou CP, Xu HB, et al. 2019 Mar. Ambient Air Pollution Is Associated With HDL (High-Density Lipoprotein) Dysfunction in Healthy Adults. Arterioscler Thromb Vasc Biol.39(3):513-522.

3.Murray CJL, Aravkin AY, Zheng P, et al. 2020 Oct 17. Global burden of 87 risk factors in 204 countries and territories, 1990-2019: a systematic analysis for the Global Burden of Disease Study 2019.Lancet.396(10258):1223-1249.

4.Soran H, Schofield JD, Durrington PN. 2015 Oct 16. Antioxidant properties of HDL. Front Pharmacol.6:222.

5.Rosenson RS, Brewer HB, Ansell BJ, et al.2016 Jan.Dysfunctional HDL and atherosclerotic cardiovascular disease. Nat Rev Cardiol.13(1):48-60.

6.Mao SY, Chen GB, Liu FF, et al. 2020 Jan. Long-term effects of ambient air pollutants to blood lipids and dyslipidemias in a Chinese rural population. Environ Pollut.256:113403.

7.Wu XM, Broadwin R, Basu R, et al. 2019 Mar 1. Associations between fine particulate matter and changes in lipids/lipoproteins among midlife women. Sci Total Environ. 654:1179-1186.

8.Zhang WL, Liu JX, Hu DY, et al. 2022 Jan 1.Joint effect of multiple air pollutants on lipid profiles in obese and normal-weight young adults: The key role of ozone. Environ Pollut.292(Pt A):118247.

9.Gaio V, Roquette R, Dias CM, et al.2019 Nov. Ambient air pollution and lipid profile: Systematic review and meta-analysis. Environ Pollut.254(Pt B):113036.

10.Kim JS, Chen ZH, Alderete TL, et al. 2019 Dec. Associations of air pollution, obesity and cardiometabolic health in young adults: The Meta-AIR study. Environ Int.133(Pt A):105180.

11.McGuinn LA, Schneider A, McGarrah RW, et al.2019 Jan.Association of long-term PM exposure with traditional and novel lipid measures related to cardiovascular disease risk. Environ Int.122:193-200.

12.Kim KN, Ha B, Seog W, et al. 2022 Mar.Long-term exposure to air pollution and the blood lipid levels of healthy young men. Environ Int.161:107119.

13.Brook RD, Rajagopalan S, Pope CA, et al.2010 Jun 1.Particulate Matter Air Pollution and Cardiovascular Disease An Update to the Scientific Statement From the American Heart Association. Circulation.121(21):2331-2378.

14.Ossoli A, Favero C, Vigna L, et al.2022 Sep 28 Body Mass Index Modulates the Impact of Short-Term Exposure to Air Particulate Matter on High-Density Lipoprotein Function. Antioxidants-Basel.11(10):1938.

15.Chen H, Samet JM, Bromberg PA, et al. 2021 Jan 7.Cardiovascular health impacts of wildfire smoke exposure. Part Fibre Toxicol.18(1):2.

16.Pan MN, Liu FF, Zhang K, et al. 2023 Sep 15. Independent and interactive associations between greenness and ambient pollutants on novel glycolipid metabolism biomarkers: A national repeated measurement study. Environ Res.233:116393.

17.Tzivian L, Winkler A, Dlugaj M, et al.2015 Jan.Effect of long-term outdoor air pollution and noise on cognitive and psychological functions in adults. Int J Hyg Environ Health. 218(1):1-11.

18.Carey IM, Anderson HR, Atkinson RW, et al. 2018 Sep 11. Are noise and air pollution related to the incidence of dementia? A cohort study in London, England. BMJ Open. 8(9): e022404.

19.Chen H, Kwong JC, Copes R, et al. 2017 Nov.Exposure to ambient air pollution and the incidence of dementia: A population-based cohort study. Environ Int.108:271-277.

20.Patterson WB, Holzhausen E, Chalifour B, et al. 2023 Oct 1. Exposure to ambient air pollutants, serum miRNA networks, lipid metabolism, and non-alcoholic fatty liver disease in young adults. Ecotoxicol Environ Saf.264:115486.

21.Gui ZH, Yang BY, Zou ZY, et al. 2020 Nov. Exposure to ambient air pollution and blood lipids in children and adolescents: A national population based study in China. Environ Pollut.266(Pt 3):115422.

22.Yang BY, Bloom MS, Markevych I, et al. 2018 Oct. Exposure to ambient air pollution and blood lipids in adults: The 33 Communities Chinese Health Study. Environ Int. 119:485-492.

23.Wang MZ, Zheng S, Nie YH, et al. 2018 Mar 30.CM-180906-1565386 Association between Short-Term Exposure to Air Pollution and Dyslipidemias among Type 2 Diabetic Patients in Northwest China: A Population-Based Study. Int J Environ Res Public Health.15(4):631

24.Yusuf S, Joseph P, Rangarajan S, et al. 2020 Mar 7. Modifiable risk factors, cardiovascular disease, and mortality in 155 722 individuals from 21 high-income, middle-income, and low-income countries (PURE): a prospective cohort study. Lancet.395(10226):795-808.

25.Johnson AA, Stolzing A. 2019 Dec.The role of lipid metabolism in aging, lifespan regulation, and age-related disease. Aging Cell.18(6): e13048.

26.Pan L, Yang ZH, Wu Y, et al. 2016 May. The prevalence, awareness, treatment and control of dyslipidemia among adults in China. Atherosclerosis. 248:2-9.

27.Peters SAE, Muntner P, Woodward M. 2019 Feb 19. Sex Differences in the Prevalence of, and Trends in, Cardiovascular Risk Factors, Treatment, and Control in the United States, 2001 to 2016. Circulation.139(8):1025-1035.

28.Zhao YH, Hu YS, Smith JP, et al. 2014 Feb.Cohort Profile: The China Health and Retirement Longitudinal Study (CHARLS). Int J Epidemiol.43(1):61-68.

29.Wei J, Li ZQ, Lyapustin A, et al. 2021.Reconstructing 1-km-resolution high-quality PM data records from 2000 to 2018 in China: spatiotemporal variations and policy implications. Remote Sens Environ.252.

30.Chen XX, Crimmins E, Hu PF, et al. 2019 Nov 1. Venous Blood-Based Biomarkers in the China Health and Retirement Longitudinal Study: Rationale, Design, and Results From the 2015 Wave. Am J Epidemiol.188(11):1871-1877.

31.Ma K, Dong Q. 2023 Jun 14. Association between sleep quality and benign prostate hyperplasia among middle-aged and older men in India. Bmc Public Health.23(1):1147.

32.Ye X, Wang M, Xia YQ, et al. 2023 May 5. Direct economic burden attributable to age-related diseases in China: An econometric modelling study. J Glob Health.13:04042.

33.Mao SY, Li SS, Wang CJ, et al.2020 May. Is long-term PM exposure associated with blood lipids and dyslipidemias in a Chinese rural population? Environ Int.138:105637.

34.de Bont J, Jaganathan S, Dahlquist M, et al.2022 Jun.Ambient air pollution and cardiovascular diseases:An umbrella review of systematic reviews and meta-analyses. J Intern Med.291(6):779-800.

35.Valdés S, Doulatram-Gamgaram V, Maldonado-Araque C, et al. 2024 Feb.Association between exposure to air pollution and blood lipids in the general population of Spain. Eur J Clin Invest.54(2): e14101.

36.Roswall N, Poulsen AH, Hvidtfeldt UA, et al.2023 Mar 1. Exposure to ambient air pollution and lipid levels and blood pressure in an adult, Danish cohort. Environ Res. 220:115179.

37.Chen ST, Lin CC, Liu YS, et al.2013.Airborne particulate collected from central Taiwan induces DNA strand breaks, Poly (ADP-ribose) polymerase-1 activation, and estrogen-disrupting activity in human breast carcinoma cell lines. J Environ Sci Health A Tox Hazard Subst Environ Eng.48(2):173-81.

38.Chen T, Jia G, Wei YJ, et al.2013 Nov 25. Beijing ambient particle exposure accelerates atherosclerosis in ApoE knockout mice. Toxicol Lett. 223(2):146-153.

39.Li RS, Navab M, Pakbin P, et al. 2013 Jun. Ambient ultrafine particles alter lipid metabolism and HDL anti-oxidant capacity in LDLR-null mice. J Lipid Res.54(6):1608-1615.

40.Zhang YZ, Zanotti I, Reilly MP, et al.2003 Aug 12. Over expression of apolipoprotein A-I promotes reverse transport of cholesterol from macrophages to feces in vivo. Circulation.108(6):661-663.

41.Li HC, Chen RJ, Cai J, et al. 2018 Nov. Short-term exposure to fine particulate air pollution and genome-wide DNA methylation: A randomized, double-blind, crossover trial. Environ Int. 120:130-136.

42.Bind MA, Lepeule J, Zanobetti A, et al.2014 Mar.Air pollution and gene-specific methylation in the Normative Aging Study: association, effect modification, and mediation analysis. Epigenetics. 9(3):448-458.

43.WHO Guidelines Approved by the Guidelines Review Committee2010. In: WHO Guidelines for Indoor Air Quality: Selected Pollutants. edn. Geneva: World Health Organization Copyright © 2010, World Health Organization.

44.Mudway IS, Kelly FJ. 2000 Feb-Apr. Ozone and the lung: a sensitive issue. Mol Aspects Med.21(1-2):1-48.