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Higher Food and Lifestyle Oxidative Balance Scores Decreases the Risk of Hypertension in Chinese Adults: A Population-Based Cross-Sectional Study

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ABSTRACT

Oxidative stress plays an important role in the development of hypertension (HTN). A population-based cross-sectional study was conducted in Fujian province of China. The construction of FoodL-OBS relied on diet and lifestyle components, which included four food and six lifestyle factors. Multivariable-adjusted logistic regression was performed to investigate the association between FoodL-OBS and the risk of HTN. A subgroup analysis was also conducted. Restricted cubic spline (RCS) regression was used to elucidate the dose-response relationship between FoodL-OBS and the risk of HTN. A total of 9578 participants were included, 3271 of whom suffered from HTN. The results of multivariable logistic regression analysis showed that the HTN risk decreased by 14% for each FoodL-OBS unit added [OR: 0.86 (0.84, 0.88), $p < 0.01$]. Compared with participants with the lowest levels of Food-L-OBS, those with the highest quartile were less likely to have HTN [0.43 (0.37, 0.50)]. Further stratified analysis showed that Food-L-OBS was negatively associated with the risk of HTN, which was statistically significant in participants in subgroups of ≤60 years, female, and no-dyslipidemia. The results of RCS showed a linear negative correlation between Food-L-OBS and HTN in men, but not in women. In conclusion, FoodL-OBS was negatively associated with HTN, and a healthy lifestyle and antioxidant-rich diet may be useful for preventing HTN.

Abbreviations: BMI, body mass index; CL, confidence interval; CVD, cardiovascular disease; DBP, diastolic blood pressure; DNA, deoxyribonucleic acid; FoodL-OBS, Food and Lifestyle Oxidative Balance Score; HTN, hypertension; OBS, oxidative balance score; OR, odds ratio; PPS, probability proportional to size; RAS, renin-angiotensin system; RCS, restricted cubic spline; SBP, systolic blood pressure; SRS, simple random sampling; WC, waist circumference.

Wenxin Qiu and Ying Han contributed equally to this work.

1 | Background

Hypertension (HTN) is a major risk factor for cardiovascular disease, with 19% of deaths worldwide attributable to elevated blood pressure [1]. Globally, the number of patients with HTN is increasing, from 648 million in 1990 to 1.278 billion in 2019 [2] and is expected to increase to 1.56 billion in 2025 [3]. In China, the burden of HTN and cardiovascular disease is increasing along with urbanization, rising incomes, and the aging of the population [4]. It is estimated that there are about 330 million patients suffering from cardiovascular diseases in China, 245 million of whom suffered from HTN [5]. Therefore, HTN is still a public health challenge worldwide.

The pathogenesis of HTN is complex and multifactorial. Previous studies have shown that oxidative stress may be one of the basic mechanisms in the development of HTN [6, 7]. Oxidative stress refers to a state of imbalance between oxidation and antioxidation in the body, which is prone to oxidation. Oxidative stress not only damages macromolecules and DNA, but also disrupts redox signals, which results in abnormal cell signaling [8, 9]. Normally, several regulatory mechanisms interact to maintain normal blood pressure, including the renin-angiotensin system (RAS), sympathetic nervous system, natriuretic peptides, sodium excretion, and endothelial cells [10]. Oxidative stress could damage these blood pressure regulators and organ functions, leading to HTN [11, 12]. In addition, oxidative stress mechanisms have been implicated in the development of a variety of diseases, such as CVD, diabetes, cancer, inflammatory diseases, and Alzheimer's disease [13].

Individual's oxidative balance is determined by the interaction of anti-oxidants and pro-oxidants. The oxidative balance score (OBS) is a way to measure exposure to anti-oxidants and pro-oxidants in diet and lifestyle, which represent the overall burden of oxidative stress [14, 15]. Antioxidant components contribute positively, whereas pro-oxidant components contribute negatively. Therefore, lower OBS values reflect higher pro-oxidant exposures. To date, there are more than 20 different OBS tools available by selecting different components or by adopting different scoring systems [16], and these tools have been extensively applied in epidemiological studies to assess associations between oxidative status and the risk of developing several chronic diseases [16]. Although numerous epidemiological studies have shown that higher OBS is associated with the decreased risk of cancer, stroke, and diabetes [17–19], the evidence for the association of OBS with risk of HTN is still limited.

In the present study, a population-based cross-sectional study was conducted to explore the relationship between FoodL-OBS and HTN in Fujian province, located in southeastern of China. The results of this study will provide evidence-based suggestions for local health departments to make public health interventions for HTN.

2 | Materials and Methods

2.1 | Study Population

The participants are permanent residents, aged ≥18 years old, living in the administrative divisions directly under control of

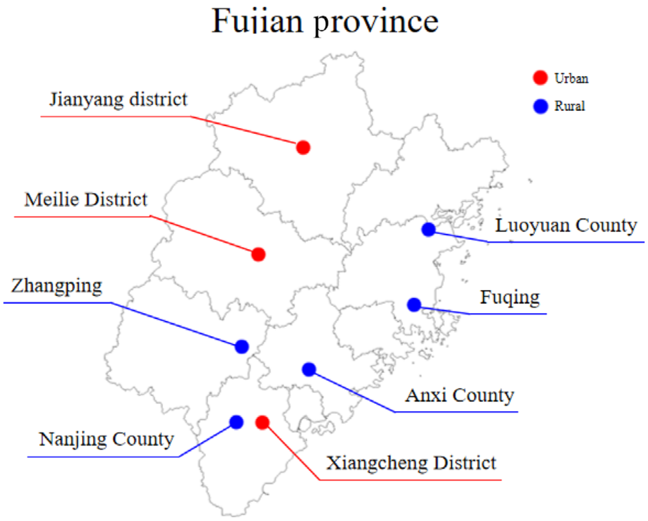

FIGURE 1 | Sampling area map of Fujian province.

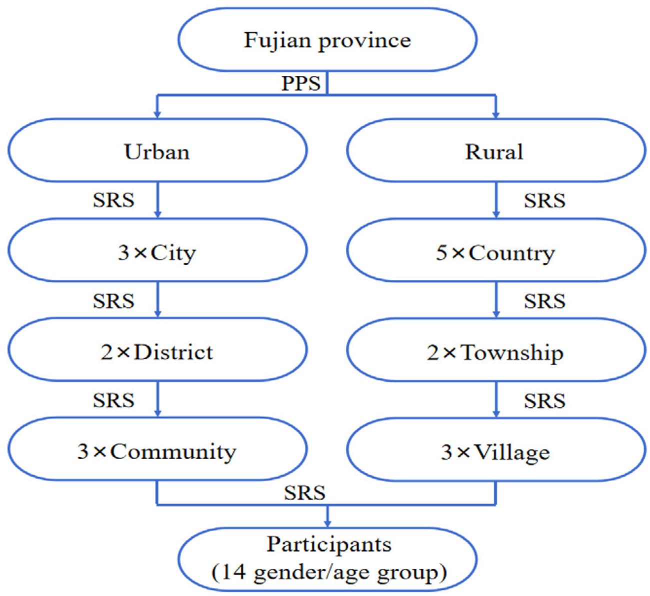

FIGURE 2 | Procedure of sampling. PPS, the probability proportional to size; SRS, the simple random sampling.

the central government throughout Fujian province. A stratified multistage random sampling method would be used to select representative samples from the general population. Briefly, three cities in urban areas and five counties in rural areas were selected using the probability proportional to size (PPS) method (Figure 1), in which two districts or two townships were selected using the simple random sampling (SRS) method. Then, three communities or villages were chosen within each district and township, respectively, using the SRS method (Figure 2). Finally, also using the SRS method, a given number of participants from each of the 14 gender/age strata (male/female and aged 18–24, 25–34, 35–44, 45–54, 55–64, 65–74, ≥75) were selected from communities or villages using the lists compiled from the local government registers of households (Table 1). The design effect was also considered while estimating the sample size. Assuming a design effect of 2 and the prevalence of HTN of 23.2% among the population aged 18 years or older, 10 172 participants

TABLE 1 | Each district/county (1200 people) all samples of neighborhood committees/villages by age groups sex survey number.

Stratified by age	The national population (%)	Number of persons to be examined = 1200 * population composition	After adjustment about the number of people required to investigate	Estimated non-response rate	Number of persons to be sampled (male/female)
18–24 years	17.02	204	200	30	286 (143/143)
25–34 years	26.75	321	250	40	416 (208/208)
35–44 years	20.70	248	230	40	384 (192/192)
45–54 years	16.24	195	200	30	286 (143/143)
55–64 years	9.62	115	120	30	172 (86/86)
65–74 years	6.60	79	100	20	126 (63/63)
≥75 years	3.06	38	100	20	126 (63/63)
Total	100	1200	1200		1796

were needed to ensure that the average lengths of the 95% confidence interval for the prevalence in the entire population and subpopulation defined by age and gender were less than 0.4% and 1.8%, respectively. As a result, a total of 9790 participants living in Fujian Province for 6 months and aged 18 years or older were randomly selected to participate in this survey from August 2020 to April 2021.

2.2 | Data Collection

Participants were required to complete a standardized questionnaire which was developed by the national coordinating center of the Fuwai Hospital (Beijing, China) through face-to-face interviews with trained staff and physical measurements. The contents included the subjects' basic personal information (sex, age, occupation, education, marital status, place of residence, family size, self-rated economic status, medical insurance, etc.), personal living habits (smoking, drinking, physical activity, regular sleep, etc.), personal medical history (HTN, diabetes, dyslipidemia, hyperuricemia, etc.), and family history of HTN. Physical examination includes measurement of height, weight, body fat, waist circumference, blood pressure, and so forth.

2.2.1 | Assessment of OBS

Based on the past research and experience [20], this study included a total of 10 FoodL-OBS components, including five pro-oxidants and five anti-oxidants. The FoodL-OBS allocation scheme is shown in Table 2. The five pro-oxidants are as follows: meat and meat products, smoking status, alcohol consumption status, obesity, and abdominal obesity. Five kinds of antioxidant factors are as follows: vegetables, fruits, fish and other aquatic products, tea consumption status, and physical activity. With the exception of an abdominal obesity status score of 0 or 1, each question scored 0, 1, or 2.

Meat and meat product intake was scored as low (2 points), moderate (1 point), and high (0 point) on the basis of quantiles for each variable. For smoking status, the scores for never smoking, occasional smoking, and regular smoking were 2, 1, and 0, respectively. For drinking status, non-drinkers, occasional drinkers and regular drinkers were assigned a score of 2, 1, and 0, respectively. Obesity, overweight, and normal were 0, 1, and 2 points, respectively. The abdominal obesity group and the normal group were assigned a score of 0 and 1, respectively.

According to the quantile of each variable, the intakes of vegetables, fruits, fish, shrimp, and crab were divided into low (0), medium (1) and high (2). For tea-drinking status, the scores were 0, 1, and 2 for never drinking tea, occasionally drinking tea, and frequently drinking tea. For physical activity, low physical activity, kind of physical activity, and high physical activity were divided into 0, 1, and 2 points. FoodL-OBS ranges from 0 to 19 points. We grouped participants by quartile according to FoodL-OBS (Q1, lowest quartile; Q2, second quartile; Q3, third quartile; and Q4, highest quartile group).

Body mass index (BMI) is defined as body mass divided by height squared (kg/m^2). According to the 2004 Chinese guidelines for the prevention and control of overweight and obesity in adults [21], BMI ≥ 28 kg/m^2 was defined as obese and BMI ≥ 24 kg/m^2 as overweight. Waist circumference (WC, cm) was measured at the midpoint between the iliac crest and the lowest rib. Abdominal obesity was defined as having a waist circumference ≥85 cm in men and ≥80 cm in women. Smoking status was classified into the following categories: never smokers, occasional smokers (smoking <1 day/week), and regular smokers (smoking ≥1 day/week). Drinking status was divided into: never drinking, occasional drinking (drinking times <1 day/week), and frequent drinking (drinking times ≥1 day/week). Tea drinking status was divided into: never drinking tea, occasionally drinking tea (tea drinking times <1 day/week), and frequent drinking tea (tea drinking times ≥1 day/week). Physical Activity: participants' physical activity levels were assessed on the basis of self-reported frequency of moderate and vigorous activity per week and then divided into three grades: low (moderate or vigorous activity less than once per week), moderate (vigorous activity once a week plus moderate activity once a week, or moderate activity 2–4 times a week) and high (vigorous activity twice a week or moderate activity more than four times a week). Each session of moderate or vigorous exercise should not be less than 40 min, the difference should be pro rata. Food intake was assessed using a simplified

TABLE 2 | Oxidative balance score assignment scheme.

OBS components	Assignment scheme[a]
Dietary components	
Vegetables(A)	0 = low (1st tertile), 1 = intermediate (2nd tertile), 2 = high (3rd tertile)
Fruits(A)	0 = low (1st tertile), 1 = intermediate (2nd tertile), 2 = high (3rd tertile)
Fish and other aquatic products(A)	0 = low (1st tertile), 1 = intermediate (2nd tertile), 2 = high (3rd tertile)
Meat and meat products(P)	0 = high (3rd tertile), 1 = intermediate (2nd tertile), 2 = low (1st tertile)
Lifestyle components	
Drinking tea status(A)	0 = never drinking tea, 1 = occasionally drinking tea (tea drinking times <1 day/week), 2 = frequent drinking tea (tea drinking times ≥1 day/week)
Physical activity(A)	0 = low (moderate or vigorous activity less than once per week), 1 = moderate (vigorous activity once a week plus moderate activity once a week, or moderate activity 2–4 times a week), 2 = high (vigorous activity twice a week or moderate activity more than 4 times a week)
Smoking status(P)	0 = regular smoker (smoking ≥1 day/week), 1 = occasional smoker (smoking <1 day/week), 2 = never smoker
Drinking status(P)	0 = frequent drinker (drinking times ≥1 day/week), 1 = occasional drinker (drinking times <1 day/week), 2 = never drinker
Overweight/obese(P)	0 = obese, 1 = overweight, 2 = normal weight
Abdominal obesity(P)	0 = abdominal obesity, 1 = normal

Abbreviations: A, anti-oxidant; P, pro-oxidant.
[a]Low, intermediate, and high categories correspond to tertile values among participants at the baseline survey.

food frequency questionnaire for vegetables, fruits, meat and meat products, fish, and other aquatic products. The education level is divided into the education level below Senior High School, Senior High School, university, and above. Participants were categorized into three groups based on their annual household income: the low-income group with an annual household income of less than RMB 20 000, the medium-income group with an income ranging from RMB 20 000 to 50 000, and the high-income group with an income exceeding RMB 50 000.

In prior studies [14, 15], multi-component OBS were constructed using various questionnaires. These scores were then successfully validated based on their correlation with circulating F2-isoprostaglandin concentrations. As a result, regardless of the weighting approach employed to generate the OBS (such as equal weight, literature-review-derived, study-data-based, or Bayesian methods), the association between OBS and health outcomes remains comparable.

2.2.2 | Blood Pressure Measurement and Definition of HTN

Blood pressure was measured with the OMRON HBP-1300 Professional Portable Blood Pressure Monitor (OMRON, Kyoto, Japan) three times on the right arm positioned at heart level after the participant was sitting at rest for 5 min, with 30 s between each measurement with an observer present. The average of the three readings was used for analysis. According to 2018 Chinese guidelines for the management of HTN, HTN was defined as follows: systolic blood pressure (SBP) ≥ 140 mm Hg, or diastolic blood pressure (DBP) ≥90 mm Hg, or treatment with anti-hypertensive drugs within 2 weeks. Stage 1 of HTN was defined as SBP 140–159 mm Hg and/or DBP 90–99 mm Hg, stage 2 as 160–179 mm Hg and/or 100–109 mm Hg, and stage 3 as ≥180 mm Hg and/or ≥110 mm Hg [22].

2.2.3 | Covariates

Based on previously published literature and biological reasons, common variables in the study included self-reported age, sex, level of education (primary or below, secondary school, university or higher), and socioeconomic level (three grades by annual income level).

2.3 | Statistical Analysis

All statistical analyses were performed after the test was normal. Data are presented as mean ± standard deviation or median (25th, 75th interquartile range) for continuous variables or number (percentage, %) for categorical variables. The Chi-square test and *t*-test were used to assess demographics characteristics in FoodL-OBS quartiles. The linear relationship between FoodL-OBS and HTN and the association between FoodL-OBS and different grades of HTN were studied by multivariable logistic regression models. After converting FoodL-OBS from continuous to categorical variables (quartiles), a trend test was used to investigate the linear correlation trend between FoodL-OBS and HTN. Subgroup analysis was used to investigate the association between FoodL-OBS and HTN in people with different sex, age, education, diabetes, and dyslipidemia, the interaction test was used to investigate the consistency of the correlation between subgroups. We applied restricted cubic spline (RCS) analysis with four knots to evaluate the non-linear associations between FoodL-OBS and HTN risk. SPSS25.0 statistical software was used for all statistical analysis. R statistical software (version 4.3.1) was applied for mapping. Alpha was set at <0.05 for statistical significance, and all analyses were two-sided. A two-sided p value < 0.05 was defined as the significance threshold.

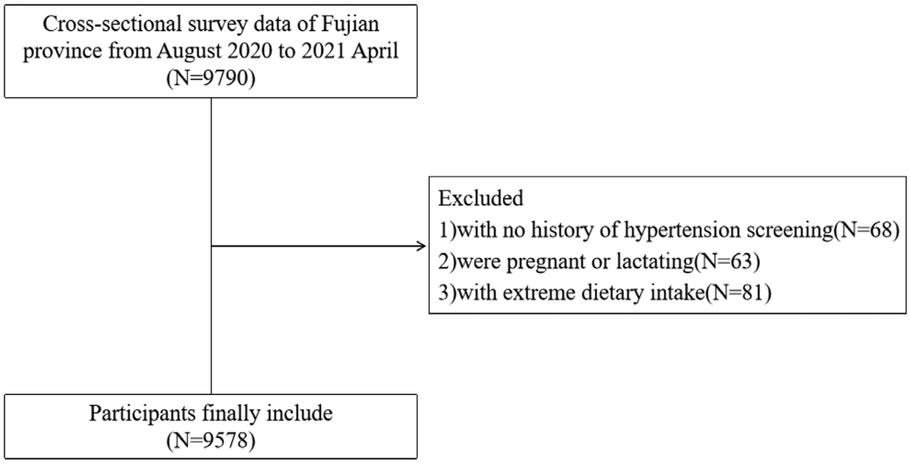

FIGURE 3 | Flow chart of participants selection.

3 | Results

As shown in Figure 3, a total of 9578 participants from 9790 eligible participants (4753 males and 4825 females; aged 18–93 years) were included in the statistical analysis. Of those, 3567 participants came from urban areas and 6011 from rural areas. Excluding 68 participants with no history of HTN screening, 63 participants who were pregnant or lactating, and 81 participants with extreme dietary intake (Figure 3).

3.1 | Baseline Characteristics

Of the 9578 participants, 3271 (34.15%) had HTN. The prevalence of HTN in male (1878, 39.51%) was higher than that in female (1393, 28.87%). Patients with HTN were older and less educated (Table 3). The comparison of baseline characteristics showed that the prevalence of diabetes, dyslipidemia, and other cardiovascular diseases was higher in patients with HTN. Compared with hypertensive patients, non-hypertensive patients had significantly higher total OBS, dietary, and lifestyle OBS. Table 4 summarizes the baseline characteristics of the FoodL-OBS quartile array study population. Compared with participants in the lowest quartile of FoodL-OBS, participants in the highest quartile of FoodL-OBS were more likely to be female and young, and to have HTN, diabetes, and other cardiovascular diseases was also lower. In terms of socioeconomic status, higher FoodL-OBS participants were more likely to have higher education and higher income. The clinical characteristics of the single FoodL-OBS component are shown in Table 5. The mean values of vegetables, fruits, meat, fish, and other aquatic products increased with the FoodL-OBS quartile. Compared with the highest quarter of FoodL-OBS participants, the lowest quarter of FoodL-OBS participants had significantly higher rates of frequent smoking, frequent alcohol consumption, never drinking tea, obesity, abdominal obesity, and low physical activity.

3.2 | Relationship Between Oxidative Balance Score and HTN

Table 6 shows the association between FoodL-OBS and HTN. We found that higher FoodL-OBS was inversely associated with HTN in both the crude model and the adjusted model, and this negative association was more pronounced in more severe HTN patients. The results of multivariable logistic regression analysis showed that the HTN risk decreased by 14% for each Food-L-OBS unit added [OR: 0.86 (0.84, 0.88), p <0.01]. After changing FoodL-OBS from continuous variable to categorical variable, sensitivity analysis was performed. In the fully adjusted model, the highest quartile of participants had a 57% lower risk of HTN, compared with the lowest quartile of FoodL-OBS [0.43 (0.37, 0.50)].

3.3 | Subgroup Analyses

Subgroup analyses and interaction tests stratified by age, sex, education level, diabetes mellitus, dyslipidemia, and other cardiovascular diseases were performed to assess whether the association between FoodL-OBS and HTN was consistent in the general population. The results show that there are still negative associations between FoodL-OBS and HTN in all subgroups. As shown in Figure 4, there was a significant interaction between age, sex, and dyslipidemia ($p_{\text{interaction}} < 0.05$), except for diabetes, education, and other cardiovascular diseases. The negative association effect of FoodL-OBS with HTN was stronger in the under-60 population [0.84 (0.82, 0.86)] and in the female population [0.82 (0.80, 0.84)]. In addition, the negative correlation effect was significantly higher in patients without dyslipidemia [0.85 (0.83, 0.86)] than in patients with dyslipidemia [0.94 (0.85, 1.05)].

3.4 | RCS Analysis

The dose-response relationship between FoodL-OBS and the risk of HTN were further evaluated using the RCS curves. First, we found a nonlinear relationship between overall FoodL-OBS and risk of HTN (p for non-linear = 0.2581) (Figure 5A). The risk of HTN decreased with increasing FoodL-OBS. Results of the RCS analysis by gender revealed that, consistent with the relationship between overall FoodL-OBS and risk of HTN, FoodL-OBS was negatively and linearly associated with the prevalence of HTN in male (p for non-linear = 0.6642). In addition, we found a nonlinear relationship (p for non-linear = 0.019) between FoodL-OBS and HTN in female (Figure 5B), with the risk of HTN decreasing with increasing FoodL-OBS, and the decrease in the

TABLE 3 | Baseline characteristics of all participants with hypertension.

Variables	Overall (n = 9578)	Non-HTN (n = 6307)	HTN (n = 3271)	p value[a]
Age (years)	44.69 ± 18.09	38.53 ± 15.35	56.56 ± 17.02	<0.001
Gender, n (%)				<0.001
Female	4825 (50.38)	3432 (71.13)	1393 (28.87)	
Male	4753 (49.62)	2875 (60.49)	1878 (39.51)	
Age group, n (%)				<0.001
<60 years	7536 (78.68)	5684 (75.42)	1852 (24.58)	
≥60 years	2042 (21.32)	623 (30.51)	1419 (69.49)	
Education, n (%)				<0.001
Less than high school	5103 (53.28)	2698 (52.87)	2405 (47.13)	
High school	1778 (18.56)	1324 (74.47)	454 (25.53)	
More than high school	2697 (28.16)	2285 (84.72)	412 (15.28)	
Diabetes, n (%)				<0.001
Yes	350 (3.65)	95 (27.14)	255 (72.86)	
No	9228 (96.35)	6212 (67.32)	3016 (32.68)	
Dyslipidemia, n (%)				<0.001
Yes	285 (2.98)	93 (32.63)	192 (67.37)	
No	9293 (97.02)	6214 (66.87)	3079 (33.13)	
Other cardiovascular diseases, n (%)				<0.001
Yes	110 (1.15)	27 (24.55)	83 (75.45)	
No	9468 (98.85)	6280 (66.33)	3188 (33.67)	
Household income, n (%)				<0.001
Low	3232 (33.74)	1823 (56.40)	1409 (43.60)	
Medium	4050 (42.28)	2814 (69.48)	1236 (30.52)	
High	2296 (23.97)	1670 (72.74)	626 (27.26)	
Oxidative Balance Score	11.33 ± 2.33	11.63 ± 2.25	10.76 ± 2.37	<0.001
Dietary OBS	3.85 ± 1.57	3.90 ± 1.56	3.73 ± 1.57	<0.001
Lifestyle OBS	6.89 ± 1.50	7.02 ± 1.44	6.62 ± 1.58	<0.001

[a] p value for the comparison of baseline characteristics of hypertension versus non-hypertension in baseline surveys. Significance was set at $p < 0.05$.

risk of HTN being more pronounced in women than in men. This is also consistent with the results of the subgroup analysis.

4 | Discussion

To our knowledge, our large-scale cross-sectional study for the first time evaluated the association of FoodL-OBS with HTN in China. In this study, we confirmed that the FoodL-OBS in participants without HTN were significantly higher than those in participants with HTN. Higher FoodL-OBS were associated with decreased risk of HTN. After confounding factors were adjusted, this negative association was stronger in patients with more severe HTN. Further stratified analysis showed that every OBS unit raised associated with a declined risk of HTN was statistically significant in participants in subgroups of ≤60 years, female, and no-dyslipidemia. The results of the RCS showed a linear relationship between OBS and HTN in males and in all participants. In females, there was a nonlinear relationship between OBS and risk of HTN. Our results suggested that increased FoodL-OBS may contribute to a reduced risk of HTN.

Most of the evidence supporting the relationship between OS and HTN comes from basic science and animal studies [23, 24]. For example, antioxidant therapy reduces oxidative stress burden and reduces the development of HTN in rats [25]. In humans, however, the results have not been entirely consistent and efficacy of antioxidant supplementation in reducing blood pressure [26–28]. An intervention trial conducted in China that showed a lower risk of HTN among men in the antioxidant supplementation group after 6 years of follow-up, but not among women [27]. However, a randomized primary prevention study did not find an association between HTN and antioxidant supplementation [28]. A large cohort study in France showed that a high-antioxidant diet was inversely associated with the risk of HTN in women [26]. One potential reason for the inconsistencies in the relationship

TABLE 4 | Baseline characteristics of all participants by the OBS quartile.

Characteristics	Oxidative Balance Score				p value[a]
	Q1	Q2	Q3	Q4	
Age(years)	46.57 ± 18.95	45.58 ± 18.68	44.01 ± 17.96	43.71 ± 17.22	<0.001
Sex, n (%)					<0.001
Male	1324 (64.05)	692 (52.18)	1534 (48.92)	1203 (39.46)	
Female	743 (35.95)	634 (47.82)	1602 (51.08)	1846 (60.54)	
Hypertension, n (%)					<0.001
Yes	977 (47.27)	509 (38.39)	1000 (31.89)	785 (25.75)	
No	1090 (52.73)	817 (61.61)	2136 (68.11)	2264 (74.25)	
Diabetes, n (%)					0.003
Yes	101 (4.89)	51 (3.85)	108 (3.44)	90 (2.95)	
No	1966 (95.11)	1275 (96.15)	3028 (96.56)	2959 (97.05)	
Dyslipidemia, n (%)					0.094
Yes	68 (3.29)	51 (3.85)	80 (2.55)	86 (2.82)	
No	1999 (96.71)	1275 (96.15)	3056 (97.45)	2963 (97.18)	
Other cardiovascular diseases, n (%)					0.004
Yes	39 (1.89)	14 (1.06)	26 (0.83)	31 (1.02)	
No	2028 (98.11)	1312 (98.94)	3110 (99.17)	3018 (98.98)	
Education level, n (%)					<0.001
Less than high school	1225 (59.26)	739 (55.73)	1640 (52.30)	1499 (49.16)	
High school	370 (17.90)	207 (15.61)	568 (18.11)	633 (20.76)	
More than high school	472 (22.84)	380 (28.66)	928 (29.59)	917 (30.07)	
Household income, n (%)					<0.001
<20 thousand yuan	781 (37.79)	489 (36.88)	1073 (34.22)	889 (29.16)	
20–50 thousand yuan	830 (40.15)	512 (38.61)	1340 (42.73)	1368 (44.86)	
>50 thousand yuan	456 (22.06)	325 (24.51)	723 (23.05)	792 (25.98)	

[a]p value for the comparison of the baseline characteristics among quartile groups of oxidative balance score at the baseline survey. Significance was set at $p < 0.05$.

between HTN and antioxidant intake in humans may be the extremely complex interactions of multiple pro- and anti-oxidant factors with endogenous enzymatic mechanisms and exogenous factors. Various exogenous factors, including diet, smoking, exercise, and medicines, affect oxidative stress [29, 30].

Therefore, oxidative balance score (OBS) has been proposed, a measure of the status of dietary and lifestyle pro- and anti-oxidant components, to be a more accurate representation of the overall OS-related exposures in an individual [14]. Given the inconclusive association between individual antioxidants and high blood pressure or HTN from previous studies, the use of OBS seems promising. A cross-sectional study using Nutrient-L-OBS to assess the association with HTN among a racially diverse population, which is the first report to reveal the relationship between OBS and HTN. In the study, there was a negative association with HTN, but none of the four biomarkers of oxidative stress was significantly associated with HTN after adjustment [31]. A subsequent study validated the Nutrient-L-OBS association with new-onset HTN in a Korean cohort, which showed a dose-dependent negative correlation between Nutrient-L-OBS and new-onset HTN, the adjusted HRS (95% CI) was 0.94 (0.92–0.97) [32]. Both studies found a negative association between nutrient-L-OBS and HTN. However, in these studies, nutrient-L-OBS calculation are complex and require conversion of food intake into nutrient intake, which is limited to implement in large-scale population surveys.

In this study, a novel FoodL-OBS developed and validated by Ángela et al. [20], which consists of five pro-oxidant components (meat and meat products, smoking status, alcohol consumption status, obesity, and abdominal obesity) and five anti-oxidant components (vegetables, fruits, fish and other aquatic products, tea consumption status and physical activity) was used to measure the status of pro-oxidants and antioxidants exposures in an individual. Consistent with previous reports, our finding showed that higher FoodL-OBS were associated with decreased risk of HTN. After confounding factors were adjusted, this negative association was stronger in patients with more severe HTN. To our knowledge, our study is the first time using FoodL-OBS tool to assess the association between OBS and the prevelence of HTN. Given that FoodL-OBS based on macro-food and was calculated

TABLE 5 | Individual components of the score by oxidative balance scores quartile.

Characteristics	Oxidative Balance Score Q1	Q2	Q3	Q4	*p*-value[a]
Vegetable_weight (g/day)	216.04 ± 221.89	256.52 ± 282.21	335.52 ± 385.29	522.99 ± 626.79	<0.001
Fruit_weight (g/day)	67.47 ± 147.39	102.04 ± 183.76	165.97 ± 284.91	312.31 ± 420.27	<0.001
Meat_weight (g/day)	185.99 ± 236.68	180.94 ± 234.64	195.02 ± 292.19	223.45 ± 334.62	<0.001
Fish_weight (g/day)	42.75 ± 128.43	65.08 ± 155.04	88.04 ± 190.38	162.68 ± 269.47	<0.001
Obesity status, *n* (%)					<0.001
Obese	619 (29.95)	184 (13.88)	264 (8.42)	77 (2.52)	
Overweight	884 (42.77)	531 (40.04)	953 (30.39)	632 (20.73)	
Normal weight	564 (27.28)	611 (46.08)	1919 (61.19)	2340 (76.75)	
Abdominal obesity, *n* (%)	1452 (70.25)	674 (50.83)	1131 (36.07)	586 (19.22)	<0.001
Smoking status, *n* (%)					<0.001
Regular smoker	754 (36.48)	295 (22.25)	524 (16.71)	269 (8.82)	
Occasional smoker	92 (4.45)	59 (4.45)	134 (4.27)	69 (2.26)	
Never smoker	1221 (59.07)	972 (73.30)	2478 (79.02)	2711 (88.92)	
Drinking status, *n* (%)					<0.001
Regular drinker	160 (7.74)	52 (3.92)	86 (2.74)	27 (0.89)	
Occasional drinker	841 (40.69)	418 (31.52)	921 (29.37)	604 (19.81)	
Non-drinker	1066 (51.57)	856 (64.56)	2129 (67.89)	2418 (79.30)	
Tea status, *n* (%)					<0.001
Non-tea drinkers	1206 (58.35)	749 (56.48)	1460 (46.56)	1053 (34.54)	
Occasional tea drinker	479 (23.17)	321 (24.21)	890 (28.38)	949 (31.13)	
Regular tea drinkers	382 (18.48)	256 (19.31)	786 (25.06)	1047 (34.34)	
Physical activity, *n* (%)					<0.001
Low (0–1 day/week)	622 (30.09)	232 (17.50)	337 (10.75)	122 (4.00)	
Moderate (2–4 days/week)	718 (34.74)	441 (33.26)	997 (31.79)	718 (23.55)	
High (5–7days/week)	727 (35.17)	653 (49.24)	1802 (57.46)	2209 (72.45)	

[a] *p* value for the comparison of the baseline characteristics among quartile groups of oxidative balance score at the baseline survey. Significance was set at $p < 0.05$.

simply, it has the potential to be a cost-effective tool in evaluating the individual´s oxidative/antioxidant status.

Gendered factors may also play a significant role in the development of HTN, and the relatively higher oxidative stress burden in men may cause sexual dimorphism in HTN [33]. In our study, subgroup analysis revealed that every FoodL-OBS unit raised associated with declined risk of HTN both in men and women. The adjusted ORs was [0.89 (0.87, 0.91)] for men and [0.82 (0.80, 0.84)] for women, showing lower OR in women. These results are similar with the study in Korean [20]. In addition, RCS analysis also showed that the dose-dependent manner in men was different from that in women. These results suggests that sex differences exist in the physiological mechanism of oxidative stress. A previous study showed that women have greater antioxidant potential compared with men [34], possibly due to gender differences in the expression and activity of antioxidant enzymes and sex hormones [35]. On the other hand, lifestyle habits (more fruits and vegetables being consumed by women) may be another important factor. In this regard, the results of the present study suggests that more anti-oxidant lifestyles and diets are needed to lower the risk of HTN in men.

It is well known that aortic stiffness increases gradually with age [36]. Excessive pressure pulsatility resulting from abnormal aortic stiffness leads to abnormalities in microvascular structure and function [37], which eventually leads to endothelial dysfunction [38], vascular remodeling [39], and consequently to elevated blood pressure. In the present study, we also found an interaction between age and HTN. The adjusted ORs was [0.84 (0.82, 0.86)] for participants with age <60 years and [0.87 (0.83, 0.90)] for participants with age ≥60 years, which suggests that age differences exist in the physiological mechanism of oxidative stress and reminds us to adjust dietary structure and lifestyle in different age to reduce risk. In addition, there are complex interactions between dyslipidemia and HTN. Both HTN and dyslipidemia are thought to be independent risk factors for arteriosclerosis [40], and there is evidence of a strong association between them [41, 42]. Dyslipidemia produces excess reactive oxygen species (Ros), which damage the endothelium [43, 44]. HTN can trigger or cause

TABLE 6 | The associations between Oxidative Balance Score and hypertension.

Exposure	OR (95% CI)		
	Model 1	Model 2	Model 3
Oxidative Balance Score (continuous)			
Total	0.85 (0.83, 0.86)	0.85 (0.84, 0.87)	0.86 (0.84, 0.88)
Stage 1 HTN	0.86 (0.84, 0.88)	0.87 (0.85, 0.89)	0.87 (0.85, 0.89)
Stage 2 HTN	0.83 (0.80, 0.86)	0.83 (0.80, 0.86)	0.84 (0.80, 0.86)
Stage 3 HTN	0.80 (0.75, 0.84)	0.80 (0.75, 0.84)	0.80 (0.75, 0.84)
p for trend	<0.001	<0.001	<0.001
Oxidative Balance Score (quartile)			
Quartile 1	reference	reference	reference
Quartile 2	0.70 (0.60, 0.80)	0.70 (0.59, 0.82)	0.70 (0.60, 0.83)
Quartile 3	0.52 (0.47, 0.59)	0.55 (0.48, 0.63)	0.57 (0.50, 0.65)
Quartile 4	0.39 (0.34, 0.44)	0.41 (0.36, 0.47)	0.43 (0.37, 0.50)
p for trend	<0.001	<0.001	<0.001

Note: Model 1: No covariates were adjusted. Model 2: Age and gender were adjusted. Model 3: Age, gender, diabetes, dyslipidemia, education level, and household income were adjusted.

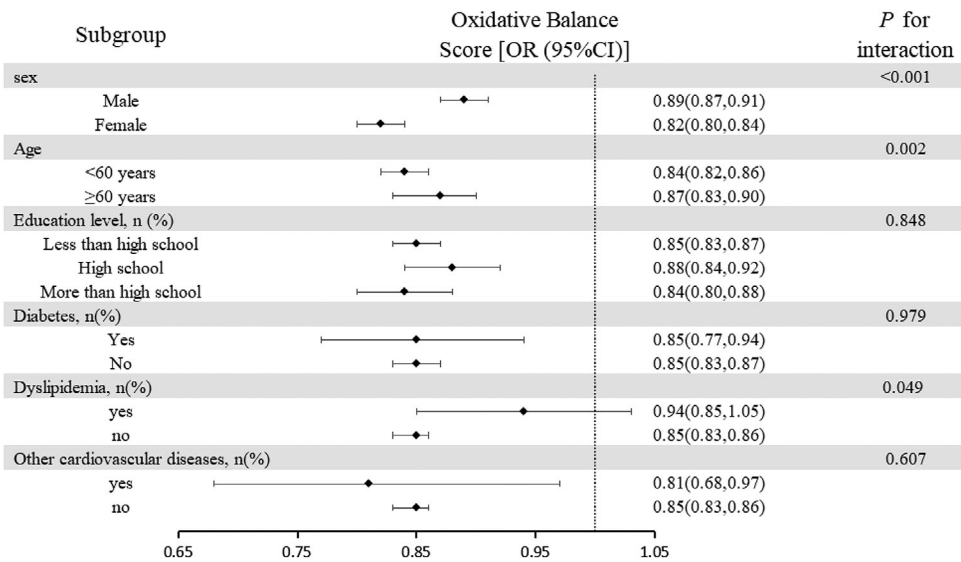

FIGURE 4 | Subgroup analysis of the association between Oxidative Balance Score and hypertension. Age, sex, education level, diabetes, dyslipidemia, and other cardiovascular diseases were adjusted. OR, odds ratio; CI, confidence interval.

the loss of vasoconstriction, which damages the endothelium [45]. In turn, endothelial damage can lead to vascular sclerosis and increase cell lipid permeability, which raises blood pressure and dyslipidemia [46].

This study has several strengths. First, our study found the association between OBS and HTN for the first time using a novel simply FoodL-OBS tool based on macro-food and it has the potential to be a cost-effective tool in evaluating the individual's oxidative/antioxidant status. Second, the population-based cross-sectional study used a stratified, multistage sampling method, which increases the generalize ability of our findings to non-institutionalized populations. Third, this study adjusted the results for several confounders. However, there are several limitations in this study. Firstly, because of the cross-sectional study design, the causal relationship between FoodL-OBS and HTN cannot be inferred. To increase the utility of our findings, the predictive value of FoodL-OBS in HTN needs to be further verified through prospective studies. Secondly, database limitations prevented the inclusion of all covariates that had an effect on oxidative stress, such as endogenous factors that alter oxidative stress (gut microbiota and genes associated with antioxidant enzymes) and environmental factors (air and water pollutants, UV radiation, pathogen infection, and extreme temperatures). However, the association between HTN and current FoodL-OBS is stable enough that it is unlikely to be significantly influenced by unincorporated factors.

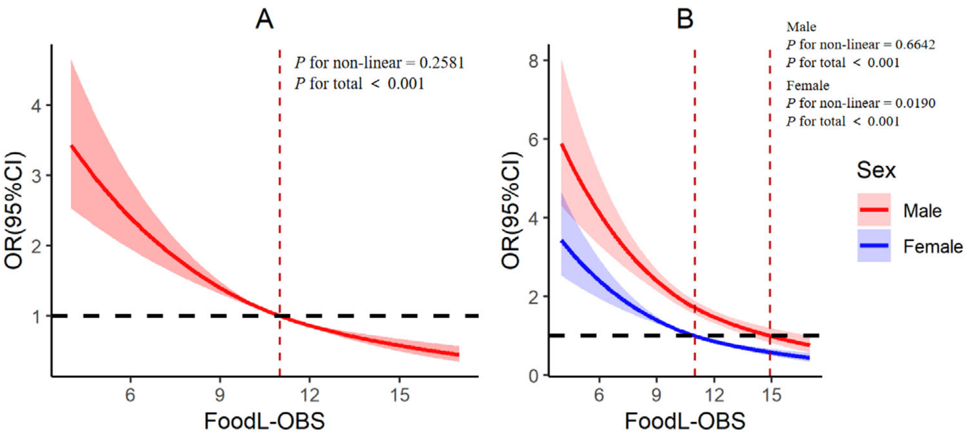

FIGURE 5 | RCS analysis of the association between FoodL-OBS and hypertension. The association was adjusted for age, gender, race, education, family income, diabetes, and dyslipidemia. (A) RCS curve of the association between FoodL-OBS and hypertension among all participants. (B) RCS curve of the association between FoodL-OBS and hypertension among female and male participants. CI, confidence interval; OR, odds ratio; RCS, restricted cubic spline.

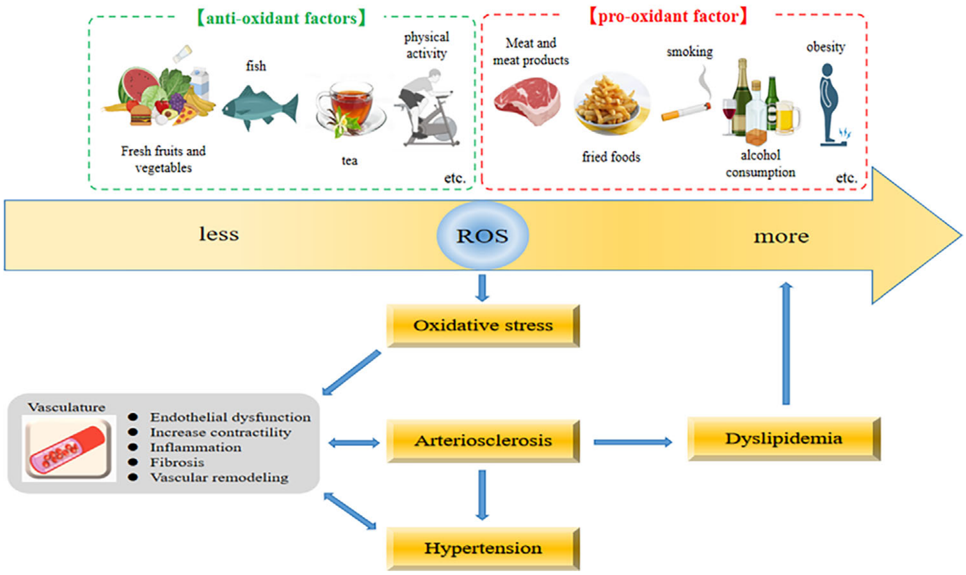

FIGURE 6 | Flowchart of the mechanism of relationship of OBS with hypertension.

5 | Conclusion

In conclusion, higher FoodL-OBS indicates that dietary and lifestyle antioxidant exposure is superior to pro-oxidant exposure and is associated with a lower risk of HTN. The possible mechanism is shown in Figure 6. Our findings suggest that a healthy lifestyle and antioxidant-rich diet to increase FoodL-OBS may help prevent HTN. However, further prospective studies are needed to validate our findings.

Author Contributions

Wenxin Qiu: Formal analysis, Methodology, Writing–original draft. Ying Han: Methodology, Funding acquisition, Writing–review & editing. Jingru Huang: Formal analysis, Writing–review & editing. Danjing Chen: Data curation, Visualization. Jiangwang Fang: Software, Writing–review & editing. Huajing Chang: Writing–review & editing. Xian-e Peng: Conceptualization, Investigation, Writing–review & editing.

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Ethics Statement

This study was approved by the Medical, Research Ethics Committee of the Fuwai Cardiovascular Hospital of Beijing, China (No 2020-1360), and the survey will be conducted in accordance with the ethical principles of the Declaration of Helsinki and the International Conference on Harmonization of Good Clinical Practice.

All participants who provided written informed consent were enrolled in the study. If the participants were unable to write, fingerprinting was used. This study was approved by the Medical, Research Ethics Committee of the Fuwai Cardiovascular Hospital of Beijing, China (No. 2020-1360), and the survey will be conducted in accordance with the ethical principles of the Declaration of Helsinki and the International Conference on Harmonization of Good Clinical Practice.

Consent

All participants who provided written informed consent were enrolled in the study. If the participants were unable to write, fingerprinting was used.

Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

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