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Association between healthy lifestyle and frailty in adults and mediating role of weight-adjusted waist index: results from NHANES

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Abstract

Background The relationship between healthy lifestyle and frailty remains unclear. Healthy weight is crucial for overall well-being, but using body mass index (BMI) to evaluate weight management is inefficient. This study clarifies the association between healthy lifestyle or its factors (non-smoking, moderate drinking, healthy weight, healthy diet, sufficeint physical activity, and non-sedentary) and frailty, and the feasibility of using the weight-adjusted waist index (WWI) reflecting central obesity as an intermediate indicator.

Methods This study included 4,473 participants from the 2007–2018 National Health and Nutrition Examination Survey (NHANES). Healthy lifestyle quality was assessed by summing the scores of each healthy lifestyle factor. Frailty was assessed using a 49-item frailty index (FI), categorizing participants into robust, pre-frail, and frail. Logistic regression to investigate the association between healthy lifestyle or its factors, WWI, and frailty. Smooth curve fitting and threshold effect analyses were used to elucidate the nonlinear association. Subgroup and two other sensitivity analyses were conducted to confirm the stability of the results. A causal mediation model examined the proportion of frailty mediated by WWI.

Results The study identified 13.98% of the participants as frail. Optimal healthy lifestyle and frailty were negatively associated (OR: 0.39, 95%CI: 0.27–0.58). Five healthy lifestyle factors (non-smoking, healthy weight, healthy diet, sufficient physical activity, and non-sedentary) were associated with a lower prevalence of frailty, with odds ratios (OR) ranging from 0.48 to 0.61. We also analyzed the association between a healthy lifestyle and WWI (OR: 0.32, 95%CI: 0.27–0.37), WWI and frailty (OR: 1.85, 95%CI: 1.59–2.16). A positive association between WWI and FI was observed beyond the inflection point (9.99) (OR: 0.03, 95%CI: 0.02–0.03). Subgroup and sensitivity analyses confirmed stable associations between healthy lifestyle, WWI, and frailty. WWI partially mediated the association between a healthy lifestyle and frailty (mediating ratio = 20.50–20.65%).

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Conclusions An optimal healthy lifestyle and positive healthy lifestyle factors are associated with a lower incidence of frailty. WWI may mediate the relationship between a healthy lifestyle and frailty.

Keywords Healthy lifestyle, Frailty, Weight-adjusted waist index, NHANES, Cross-sectional study

Background

Frailty is a multifactorial clinical syndrome characterized by the inability of the body to cope with daily or acute stressors because of the increased vulnerability to age-related decline in physiological reserves and function of multiple organ systems [1, 2]. Frailty heightens the risk of disability and/or mortality due to elevated rates of falls and cognitive decline [3]. The adverse consequences of frailty also include limitations in activities of daily living, hospitalizations, and in severe cases, premature mortality [4, 5]. Previous studies indicate that frailty prevalence among community-dwelling individuals aged over 65 years ranges from 10 to 20%, with an escalation with advancing age [6, 7]. While a universally accepted gold standard for frailty measurement is lacking, several assessment tools have been developed to facilitate evaluation. One prominent tool utilizing deficit accumulation is the frailty index (FI), offering a comprehensive assessment encompassing chronic diseases, activities of daily living, medications, and laboratory parameters [8]. Various studies have shown that frailty and its adverse effects can be avoided or improved by increasing physical fitness through regular exercise, taking appropriate nutritional supplements, and increasing awareness about healthy habits [9, 10]. This emphasis is heightened by evidence demonstrating that proactive health interventions can increase the likelihood of frail individuals reverting to their pre-frail state by 18% [11]. Furthermore, with the global elderly population expanding and projected to continue growing in the foreseeable future, it is imperative to prioritize proactive frailty prevention as a pivotal public health initiative.

A healthy lifestyle, characterized by modifiable and cost-effective daily behaviors, has garnered increasing attention due to its potential health-related benefits. A healthy lifestyle is usually assessed based on the following six factors: non-smoking, moderate drinking, healthy weight, healthy diet, sufficient physical activity, and non-sedentary [12, 13]. A healthy lifestyle can prolong the healthy life span and reduce the risk of all-cause mortality among older adults [14]. However, there has been limited research investigating the association between a healthy lifestyle and frailty. Several population-based cross-sectional and cohort studies have demonstrated associations between a healthy lifestyle and the incidence of multiple chronic diseases such as heart failure, stroke, and diabetes [15–17]. Frailty and chronic systemic diseases have similar epidemiological risk factors and biological mechanisms, so unhealthy lifestyles may exacerbate frailty [18]. Previous studies have primarily examined the impact of individual lifestyle factors on frailty [19–21]. Given that a healthy lifestyle encompasses multiple interrelated factors, it is crucial to elucidate the relationship between a healthy lifestyle and frailty.

Weight management is an important factor in a healthy lifestyle. Maintaining a healthy weight can delay the onset of various chronic diseases, such as diabetes and heart disease [22]. Currently, body mass index (BMI) is commonly used as a classic measure of body weight. However, BMI does not account for differences in muscle mass and fat distribution, which describe how muscles and fat are distributed in the body. Hence, BMI may be considered more suitable to obtain a rough assessment of obesity [23, 24]. Some studies have reported a paradoxical finding that obese or overweight patients, identified using BMI (≥ 30) as an assessment index, have higher survival rates than those of individuals with normal body weight under certain disease conditions. This contradicts the commonly held view that obesity accelerates aging and shortens life expectancy [25, 26]. Therefore, to circumvent the limitations of using BMI as a body weight index, the weight-adjusted waist index (WWI), a novel anthropometric index, has been proposed. WWI can better reflect central obesity without being impacted by body weight [27]. It evaluates the composition of abdominal fat and muscle mass and assesses age-related changes in the muscle and abdominal fat composition [28]. Compared to other indices of central obesity such as waist circumference, waist-to-hip ratio, A Body Shape Index (ABSI), and Body Roundness Index (BRI), WWI offers a more straightforward calculation method and avoids variability caused by changes in body shape [29]. Studies have demonstrated links between WWI and chronic systemic diseases associated with frailty, such as hypertension and hyperuricemia [30]. Therefore, WWI could potentially be associated with frailty and a healthy lifestyle. However, further clarification is needed.

To address the current research gap, we aim to systematically demonstrate the association between a healthy lifestyle or its factors and frailty in adults. We also discuss the feasibility of using WWI as an intermediate indicator.

Methods

Study design and population

We obtained the data for this study from the 2007–2018 National Health and Nutrition Examination Survey (NHANES), conducted by the Centers for Disease Control and Prevention (CDC), USA. NHANES is a

cross-sectional survey for assessing the health and nutritional status of non-institutionalized civilians. Trained interviewers and testers collected self-reported data from participants using a computer-assisted personal interview system. Before data collection, each participant provided written, informed consent. The NHANES program was approved by the Ethics Review Board of the NCHS.

We extracted the data on participants from the 2007–2018 NHANES, which included six consecutive survey cycles. A total of 59,842 participants were included. We excluded the participants under 20 years of age (N=25,072), pregnant participants (N=372), and those with incomplete data (N=29,925, including 387 with missing covariates). Therefore, our final analysis included a comprehensive dataset of 4,473 eligible participants (Fig. 1).

Healthy lifestyle

Detailed information regarding participants' lifestyles was obtained through their self-reported questionnaires. In reference to previous studies, we selected six representative healthy lifestyle factors (non-smoking, moderate drinking, healthy weight, healthy diet, sufficient physical activity, and non-sedentary behavior) [13, 31]. We defined non-smoking as less than 100 cigarettes in a lifetime, and moderate drinking as ≤ 1 drink per day for women and ≤ 2 drinks per day for men. Dietary information was collected using a face-to-face 24-hour dietary

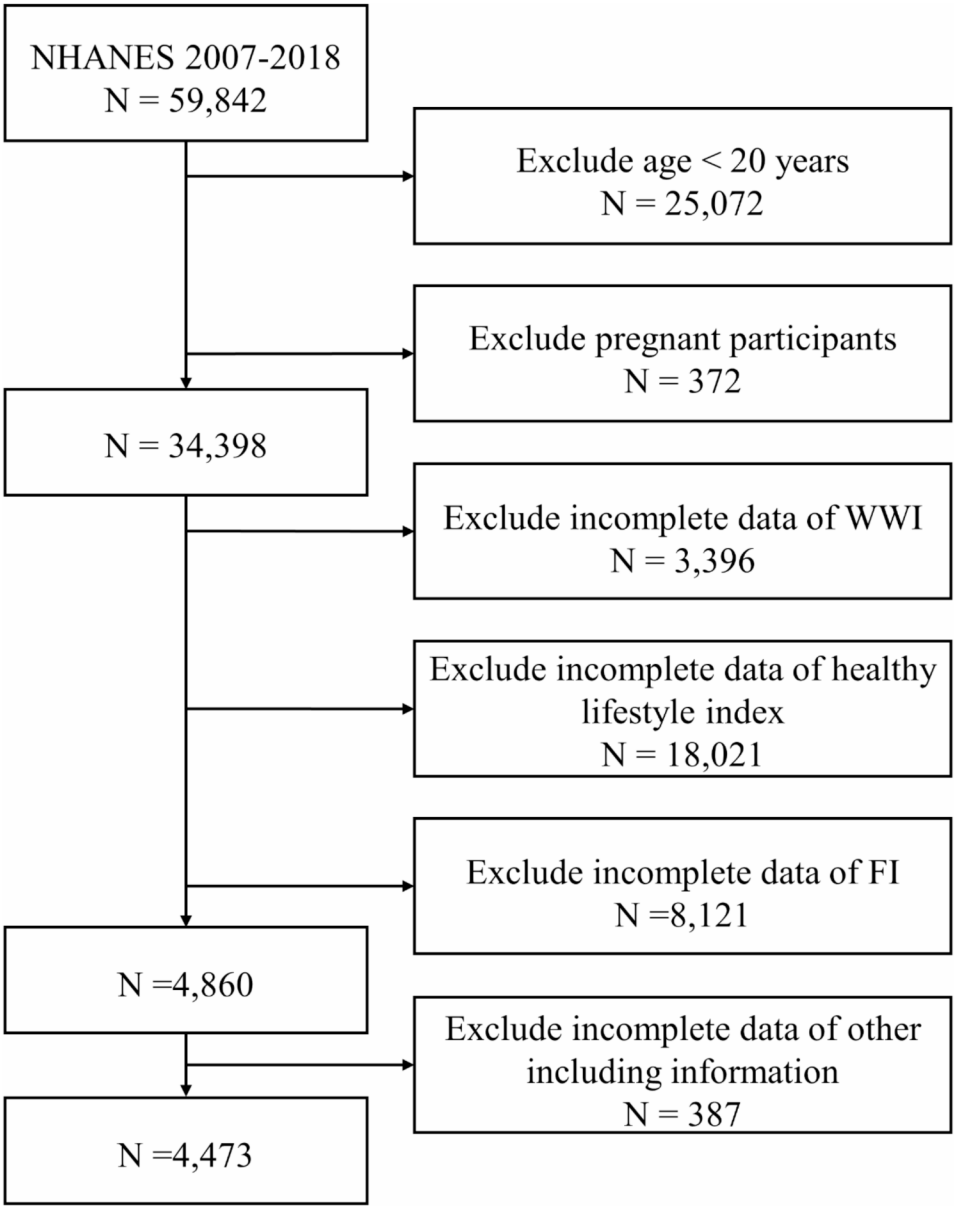

Fig. 1 Flow chart of study participants

recall followed by a second recall via phone 3–10 days later. We used the Healthy Eating Index-2015 (HEI-2015), developed by the US Department of Agriculture (USDA), which scores adherence to 13 dietary recommendations on a scale of 0–100 (Table S1). We defined a healthy diet as an average HEI-2015 score derived from two recalls that ranked within the top two-fifths of scores. BMI was calculated by dividing weight (in kilograms) by the square of height (in meters), and a healthy weight was defined as $18.5 \leq BMI < 24.9$. Total physical activity was assessed based on minutes per week of moderate-intensity activity, with sufficient physical activity defined as ≥150 min of moderate-intensity activity per week, ≥ 75 min of vigorous-intensity activity per week, or an equivalent combination of both. Non-sedentary was defined as ≤ 360 min/day sedentary while awake. Each healthy lifestyle factor meeting these criteria was scored 1 point, and those not were scored 0. Thus, a healthy lifestyle was scored within a total range of 0–6: optimal (5–6 points), intermediate (3–4 points), and poor (0–2 points) categories were defined based on these scores.

WWI

WWI is an anthropometric indicator based on waist circumference and body weight for assessing central obesity and fat distribution [27]. It is calculated as the waist circumference (in centimeters) of each participant divided by the square root of body weight (in kilograms) and rounded to two decimal places.

FI

We adopted the FI, proposed by Rockwood et al. [32], to assess frailty. We referenced the study by Hakeem et al. [33], with detailed scoring criteria provided in Table S2. The FI included 49 potential deficits encompassing cognition, dependence, depressive symptoms, comorbidities, hospital utilization, and laboratory values. The FI score is typically calculated by dividing the number of deficits by the total number of potential deficits. To ensure rigor, participants with fewer than 39 valid data points were excluded. Based on previous research, the different states of frailty were defined based on the FI score: frail as $FI \geq 0.25$, pre-frail as $0.12 \leq FI < 0.25$, and robust as $FI < 0.12$. The robust and pre-frail groups were also combined as non-frail [1, 34].

Covariates

Multivariate adjustment models were employed to account for potential confounding covariates influencing the relationship between healthy lifestyle or its factors, WWI, and frailty. We employed the following covariates: age (continuous in years), gender (male, female), race (non-Hispanic white, non-Hispanic black, Hispanic, other), education level (less than high school, high school, some college/associate education, college graduate or higher), poverty-to-income ratio (<1.31, 1.31–3.50, > 3.50), marital status (married/living with a partner, never married, widowed/divorced/separated), and insurance status [35, 36]. Data on these covariates were obtained from participant questionnaires. Detailed descriptions and measurement methodologies for each covariate can be found on the NHANES official website (https://www.cdc.gov/nchs/nhanes/).

Statistical analysis

The data were analyzed according to CDC guidelines. A Chi-square test of categorical variables and a T-test of continuous variables were used to analyze the baseline characteristics stratified by frailty status. All percentages and means were weighted using NHANES sample weights (WTMEC2YR). Prior to analysis, collinearity among variables was checked using stepwise regression. Logistic regression was used to evaluate the relationship between healthy lifestyle, WWI, and frailty across three multivariable models. Model 1 was unadjusted, model 2 adjusted for gender, age, and race; and model 3 adjusted for all covariates. Generalized additive models and smoothed curve fitting were used to check for potential nonlinear relationships. When nonlinearity was observed, a two-stage regression analysis was used to fit the threshold effect for each interval. Subgroup analyses and interaction tests were conducted based on age group (20–49, 50–69, 70–), gender, and race (non-Hispanic white, non-Hispanic black, Hispanic, and others). Additionally, WWI was converted from a continuous variable to a categorical variable by using quartiles of WWI to further validate the conclusions. Sensitivity analyses included: (1) unweighted logistic regression analyses, and (2) multiple imputation using the "mice" R package to handle missing demographic data ($n=387$), creating 5 imputed datasets for logistic regression analyses. In addition, mediation analysis was performed using the parallel mediation model. The percentage of mediation effects is calculated by dividing the estimate of the indirect effect by the sum of the estimate of the indirect effect and the estimate of the direct effect. All analyses were conducted using R 4.2.0 and EmpowerStats 4.2, and $P<0.05$ was considered statistically significant.

Results

Characteristics of participants

The baseline characteristics of participants are listed in Table 1. A total of 4,473 participants were included, with a weighted mean age of 58.53 (SD 0.75) years. Gender distribution was relatively balanced, with 51.91% males and 48.09% females. Participants were divided into three groups: robust ($N=1,734$, 42.20%), pre-frail ($N=2,013$, 43.82%), and frail ($N=726$, 13.98%).

Table 1 Descriptive baseline characteristics of participants based on their frailty states

Characteristics	All participants	Non-frail		Frail	*P*-value
		Robust	Pre-frail		
***N*(%)**	4473 (100%)	1734 (42.20%)	2013 (43.82%)	726 (13.98%)	
Age (year), mean (SE)	58.53 (0.75)	58.30 (0.94)	59.07 (1.10)	57.50 (1.35)	< 0.001
Age group, *N*(%)					< 0.001
20–49	576(14.63%)	249(15.98%)	254(14.55%)	73(10.78%)	
50–69	1959(44.53%)	746(44.09%)	805(41.20%)	408(56.33%)	
70–	1938(40.84%)	739(39.93%)	954(44.25%)	245(32.89%)	
Gender, female, *N*(%)	1962(48.09%)	692 (43.79%)	889 (48.80%)	381 (58.84%)	< 0.001
Race/Ethnicity, *N*(%)					< 0.001
Non-Hispanic white	2470(80.45%)	978 (84.06%)	1118 (79.78%)	374 (71.67%)	
Non-Hispanic black	870(7.80%)	275 (5.14%)	417 (8.63%)	178 (13.23%)	
Hispanic	410(3.54%)	174 (3.52%)	182 (3.67%)	54 (3.20%)	
Other	723(8.21%)	307 (7.28%)	296 (7.92%)	120 (11.91%)	
Education level, *N*(%)					< 0.001
Less than high school	799(10.17%)	242 (7.27%)	356 (10.07%)	201 (19.22%)	
High school	1040(22.98%)	345 (19.74%)	508 (24.12%)	187 (29.19%)	
Some college/associate education	1426(32.86%)	529 (29.20%)	658 (36.02%)	239 (34.00%)	
College graduate or more	1208(33.99%)	618 (43.78%)	491 (29.78%)	99 (17.59%)	
Marital status, *N*(%)					< 0.001
Married/living with partner	2672(64.33%)	1151 (69.89%)	1171 (63.06%)	350 (51.51%)	
Never married	544(11.46%)	196 (11.28%)	262 (11.73%)	86 (11.21%)	
Widowed/divorced/separated	1257(24.21%)	387 (18.83%)	580 (25.21%)	290 (37.28%)	
Income-to-poverty ratio, *N*(%)					< 0.001
< 1.31	823(12.01%)	204 (6.88%)	379 (12.77%)	240 (25.26%)	
1.31–3.50	1763(32.23%)	629 (27.67%)	793 (32.16%)	341 (46.24%)	
> 3.50	1887(55.75%)	901 (65.45%)	841 (55.08%)	145 (28.60%)	
Health insurance, yes, *N*(%)	3886(89.65%)	1483 (89.71%)	1767 (90.05%)	636 (88.21%)	0.103
Healthy lifestyle, *N*(%)					< 0.001
Poor	989(20.96%)	270 (16.31%)	475 (21.77%)	244 (32.49%)	
Intermediate	2390(53.41%)	920 (50.89%)	1095 (56.45%)	375 (51.51%)	
Optimal	1094(25.62%)	544 (32.80%)	443 (21.78%)	107 (15.99%)	
Non-smoking, yes, *N*(%)	1831(44.00%)	824 (51.80%)	784 (40.80%)	223 (30.47%)	< 0.001
Moderate drinking, yes, *N*(%)	2541(58.84%)	984 (58.09%)	1154 (59.81%)	403 (58.04%)	0.697
Healthy weight, yes, *N*(%)	2706(60.55%)	1188 (68.51%)	1180 (58.62%)	338 (46.56%)	< 0.001
Healthy diet, yes, *N*(%)	2200(49.04%)	929 (51.93%)	995 (49.02%)	276 (40.38%)	< 0.001
Sufficient physical activity, yes, *N*(%)	3523(80.04%)	1447 (83.78%)	1550 (78.72%)	526 (72.86%)	< 0.001
Non-sedentary, yes, *N*(%)	2978(63.02%)	1212 (69.90%)	1311 (65.13%)	455 (62.67%)	< 0.001
WWI, mean (SE)	11.18 (0.03)	11.02 (0.05)	11.24 (0.04)	11.51 (0.08)	< 0.001

WWI, weight-adjusted waist index. Values are presented as weighted means (SE) and unweighted frequencies (weighted percentages, %)

Significant differences in healthy lifestyles across frailty states were observed ($P<0.001$). Specifically, five healthy lifestyle factors, including non-smoking, healthy weight, healthy diet, sufficient physical activity and non-sedentary, showed significant variations among different frailty states (all $P<0.001$). The mean level of WWI was 11.18 (SD 0.03) and increased with higher frailty states [robust: 11.02 (SD 0.05); pre-frail: 11.24 (SD 0.05); frail: 11.51 (SD 0.08); $P<0.001$]. Frail participants tended to be older, non-Hispanic black, female, widowed/divorced/separated, with a lower education level and family incomes.

Association between healthy lifestyle and frailty

We conducted a weighted logistic regression analysis to explore the association between healthy lifestyle and frailty states (Table 2). Optimal healthy lifestyle was significantly associated with a lower frailty incidence ($P<0.001$). After adjusting for covariables, this association remained statistically significant ($P<0.001$). Compared to those with poor healthy lifestyles, participants adhering to an optimal healthy lifestyle had only a 39% risk of frailty (OR: 0.39, 95%CI: 0.27–0.58).

Table 2 Association between healthy lifestyle and frailty states, weighted

Exposure	Model 1	Model 2	Model 3
Healthy lifestyle	[OR (95% CI)]	[OR (95% CI)]	[OR (95% CI)]
Poor	Reference	Reference	Reference
Intermediate	0.56 (0.44, 0.72)	0.57 (0.44, 0.74)	0.61 (0.45, 0.81)
Optimal	0.35 (0.25, 0.48)	0.34 (0.24, 0.27)	0.39 (0.27, 0.58)
P for trend	< 0.001	< 0.001	< 0.001

Model 1: No covariates were adjusted. Model 2: Age, gender, and race were adjusted. Model 3: Age, gender, race, education level, poverty-to-income ratio, marital status, and insurance status were adjusted

Association between healthy lifestyle factors and frailty

We assessed the association between different single healthy lifestyle factors and frailty status (Fig. 2). After adjusting for all covariates, we observed that frail participants, compared to those robust, exhibited significantly lower associations with five healthy lifestyle factors: non-smoking (OR: 0.53, 95%CI: 0.40–0.70), healthy weight (OR: 0.48, 95%CI: 0.36–0.63), healthy diet (OR: 0.60, 95%CI: 0.45–0.79), sufficient physical activity (OR: 0.61, 95%CI: 0.45–0.82), and non-sedentary (OR: 0.53, 95%CI: 0.41–0.68). However, no association was observed between moderate drinking and frailty.

Association of WWI with healthy lifestyle and its factors

We assessed the association of WWI with healthy lifestyle and its factors through weighted multinomial logistic regression. A significant negative association between healthy lifestyle and WWI was founded. After adjusting for all the covariates, the association remained significant (OR: 0.32, 95%CI: 0.27–0.37) (Table S3). Five healthy lifestyle factors were found to be negatively associated with the highest quartile of WWI (versus quartile 1): non-smoking (OR: 0.85, 95%CI: 0.76–0.95), healthy weight (OR: 0.22, 95%CI: 0.18–0.26), healthy diet (OR: 0.69, 95%CI: 0.59–0.81), sufficient physical activity (OR: 0.79, 95%CI: 0.69–0.92), and non-sedentary (OR: 0.82, 95%CI: 0.72–0.95) (Fig. 3).

Association between WWI and frailty

Table 3 presented the association between WWI and frailty risk based on weighted logistic regression. After adjusting for all covariates, each 1 unit increase in WWI was associated with an 85% higher risk of frailty (95% CI: 1.59–2.16), consistent with findings from quantile analysis (quantile 4 vs. quantile 1, OR: 3.09, 95%CI: 2.22–4.31).

Generalized additive models and smoothed curve fitting were employed to confirm the nonlinear relationship between WWI and FI (Fig. 4). Using the fully adjusted model, the inflection point of WWI was identified at 9.99 (Table 4). For WWI > 9.99, frailty increased by 0.03 units per 1 unit increase in WWI (OR: 0.03, 95% CI: 0.02–0.04, $P < 0.001$). However, when WWI was < 9.99, this relationship was not significant ($P = 0.088$). Therefore, our study indicated a nonlinear positive association between WWI and FI.

Sensitivity analysis

To further examine the robustness of the association between healthy lifestyle, WWI and frailty states across different demographic groups and to identify potential population-specific factors, we conducted subgroup

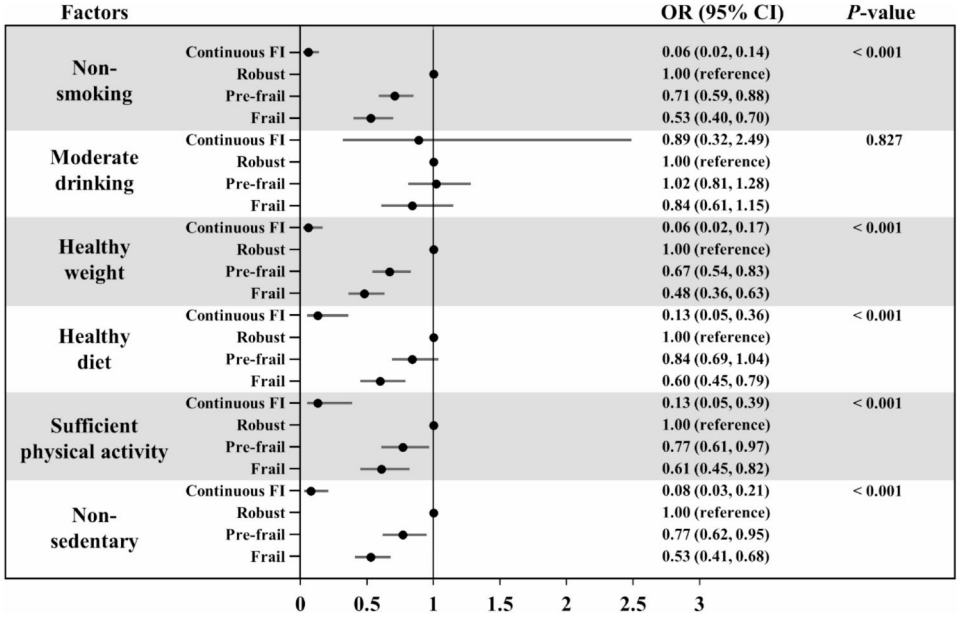

Fig. 2 OR (95% CI) in healthy lifestyle factors associated with frailty states, weighted. Models were adjusted for age, gender, race, education level, poverty-to-income ratio, marital status, and insurance status. FI, frailty index

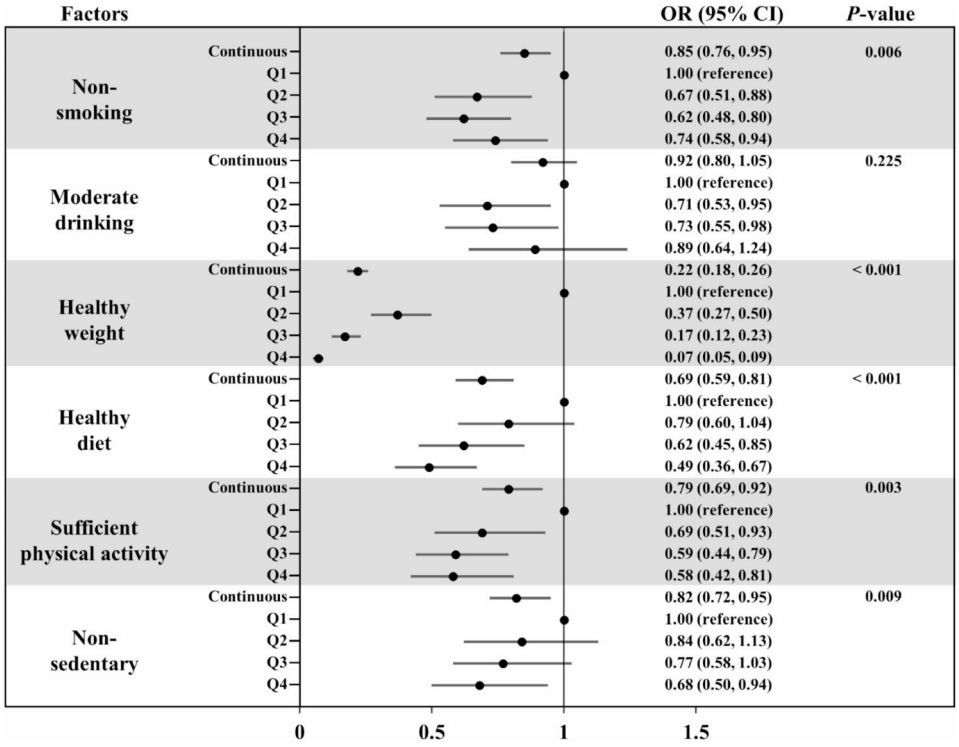

Fig. 3 OR (95% CI) in healthy lifestyle factors associated with WWI, weighted. Models were adjusted for age, gender, race, education level, poverty-to-income ratio, marital status, and insurance status. Q, quartile

Table 3 Association between WWI and frailty states, weighted

Exposure	Model 1	Model 2	Model 3
WWI	[OR (95% CI)]	[OR (95% CI)]	[OR (95% CI)]
Continuous	1.98 (1.71, 2.30)	2.15 (1.85, 2.50)	1.85 (1.59, 2.16)
Q1	Reference	Reference	Reference
Q2	1.45 (1.03, 2.04)	1.68 (1.17, 2.40)	1.57 (1.09, 2.25)
Q3	1.78 (1.24, 2.56)	2.05 (1.40, 2.99)	1.72 (1.16, 2.56)
Q4	3.46 (2.53, 4.74)	4.11 (2.96, 5.70)	3.09 (2.22, 4.31)
P for trend	< 0.001	< 0.001	< 0.001

Model 1: No covariates were adjusted. Model 2: Age, gender, and race were adjusted. Model 3: Age, gender, race, education level, poverty-to-income ratio, marital status, and insurance status were adjusted. WWI, weight-adjusted waist index

Table 4 Threshold effect analysis of weight-adjusted waist index and frailty

Standard linear model	OR (95% CI) *P* for trend	0.02 (0.02, 0.03) < 0.001
Two-piecewise linear model	Inflection point	9.99
	OR1 (< 9.99)	-0.02 (0.05, 0.00) 0.088
	OR2 (> 9.99)	0.03 (0.02, 0.03) < 0.001
	OR2/OR1	0.05 (0.00, 0.03) < 0.001
	Logarithmic likelihood ratio test *P*-value	< 0.001

Models were adjusted for age, gender, race, education level, poverty-to-income ratio, marital status, and insurance status

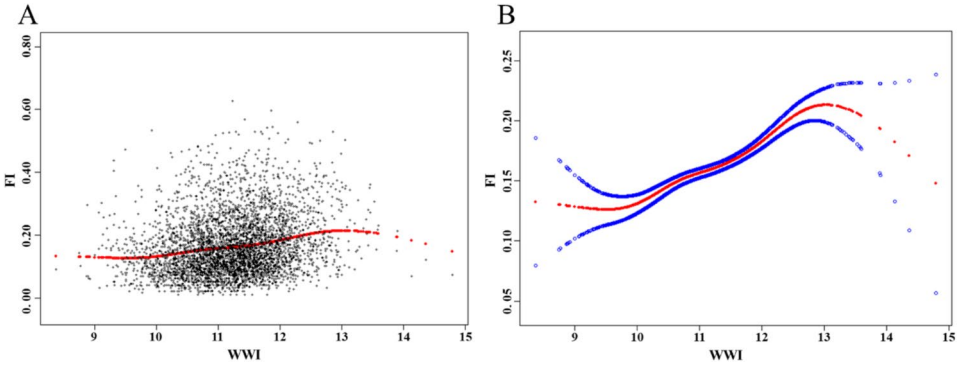

Fig. 4 Association between WWI and FI. Models were adjusted for age, gender, race, education level, poverty-to-income ratio, marital status, and insurance status. (**A**) Each black point represents a sample. (**B**) The red line represents the estimated values. The blue bands represent 95% CIs. FI, frailty index; WWI, weight-adjusted waist index

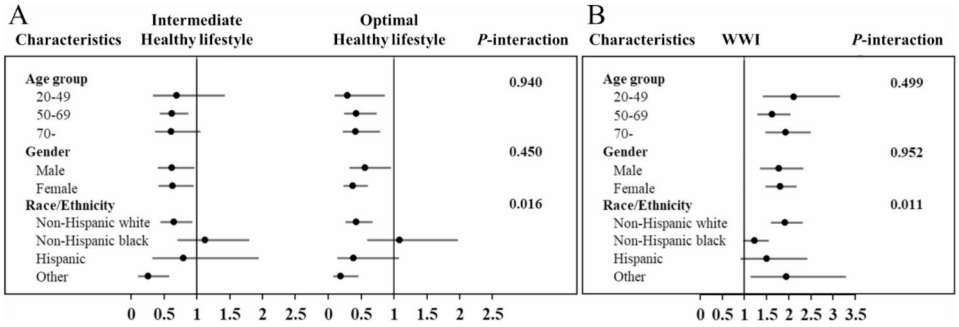

Fig. 5 Forest plots of weighted subgroup analyses of healthy lifestyle and frailty. (A) WWI and frailty. (B) Age group, gender, race, education level, poverty-to-income ratio, marital status, and insurance status were all adjusted, except for the variable itself. WWI, weight-adjusted waist index

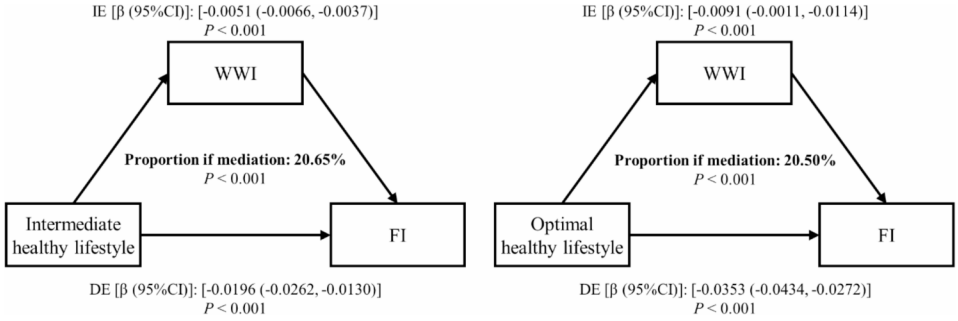

Fig. 6 Weighted estimated proportion of the association between healthy lifestyle and frailty mediated by WWI. Models were adjusted for age, gender, race, education level, poverty-to-income ratio, marital status, and insurance status. IE, estimate of the indirect effect; DE, estimate of the direct effect; the proportion of mediation = IE/DE + IE; WWI, weight-adjusted waist index

analyses and interaction tests based on the age group, gender, and race (Fig. 5). The interaction test between race and healthy lifestyle was significant (P=0.016), while that for other variables was not (P>0.05). Similarly, the interaction test between race and WWI was significant (P=0.011). In addition, we found that the association between a healthy lifestyle and frailty (OR: 1.94, 95%CI: 1.14–3.29) and that between the WWI and frailty (OR: 0.18, 95%CI: 0.07–0.46) were more significant within the race group classified as "others." Notably, this significant interaction was not observed in the subgroup analyses of the association between WWI quartiles and frailty (Table S4). Sensitivity analyses confirmed robust results: (1) unweighted logistic regression analyses of the samples; (2) logistic regression analyses using estimates from multiply imputed datasets (Table S5-Table S8).

Mediation analysis

We conducted weighted mediation analyses to assess the potential mediating role of WWI in the association between healthy lifestyle and frailty. As shown in Fig. 6, WWI significantly mediated the association between healthy lifestyle and frailty, with mediating proportions of 20.65% and 20.50%, respectively (P<0.001).

Discussion

This is the first cross-sectional study on the association between healthy lifestyle and frailty in American adults. We used WWI as an intermediary indicator to assess the health status across different levels of healthy lifestyles and to guide public health prevention efforts. We found that an optimal healthy lifestyle was strongly associated with reduced incidence of frailty and lower WWI. Specifically, non-smoking, healthy weight, healthy diet, sufficient physical activity, and non-sedentary as healthy lifestyle factors significantly associated with a lower incidence of frailty and lower WWI. We confirmed a nonlinear association between WWI and FI by using a generalized additive model and smooth curve fitting, identifying an inflection point at WWI of 9.99. These associations remained consistent after adjusting for age and gender, although they varied among different race groups. Mediation analysis demonstrated that WWI significantly mediated the association between healthy lifestyle and frailty. These observational findings suggest that a healthy lifestyle may contribute to lower prevalence of frailty, and WWI, as an indicator of central obesity, may be a suitable tool in assessing frailty.

Frailty is increasingly recognized as a significant global health challenge, associated closely with adverse health outcomes. Assessing frailty in clinical settings can aid in preventing its progression among patients [4]. We

utilized the FI proposed by Rockwood et al. to assess frailty [32]. This index quantifies frailty through the accumulation of frailty-related defects and is a continuous score that includes signs, symptoms, and laboratory indicators. Similar to the study by Jayanama et al. [37]. , we expanded the age range of the participants to include all adults ≥ 20 years of age. We identified 13.98% of the participants as frail based on their FI score. It is noteworthy that among participants aged 20 to 49 years, 10.78% were identified with frailty, highlighting the presence of frailty in younger adults. Frailty in this age group is commonly attributed to severe illnesses, trauma, and possibly genetic predispositions [38]. With the increasing trend of unhealthy behaviors, such as nutrient-deficit diets and obesity, are also responsible for increasing the incidence of frailty among younger individuals [13].

Although strategies for managing and intervening in frailty are gradually developing, more large-scale studies are needed to obtain robust evidence on the importance of frailty management and to identify additional indicators for assessing frailty [39]. In our study, we found that participants with an optimal healthy lifestyle had a 39% lower risk of frailty compared to those with poor healthy lifestyles. Our study also confirmed the association between healthy lifestyle factors (non-smoking, healthy weight, healthy diet, sufficient physical activity, and non-sedentary) and frailty, aligning with primary prevention measures proposed by Hoogendijk et al. [4]. Similar results have been observed in previous studies on healthy lifestyles. For example, a study by May et al. [14]. involving 33,000 participants aged 20–70 years found that participants who did not smoke, had BMI ≤ 25, exercised, and followed a Mediterranean diet were associated with an additional two years of healthy life compared to those without a healthy lifestyle. Stenholm et al. [40]. studied individuals aged 50–75 years and found that those without health risk factors such as smoking, physical inactivity, and obesity had an average healthy life span of 8 years. Smoking was prevalent among frail patients in our study, with only 30.47% considered non-smokers, compared with 44.00% of the robust group. In addition, 27.14% and 37.33% of frail participants were considered to have insufficient physical activity and sedentary lifestyles, respectively. A sedentary lifestyle is associated with higher mortality in people who are susceptible, weak, or physically inactive [41]. In addition, insufficient physical activity in frail patients can impair their activities of daily living [42]. We did not find an association between drinking behavior and frailty, probably due to our strict definition of moderate drinking. Shah et al. [43]. , in their study on 9,499 people over 65 years without stroke, reported that those who consumed 1–7 drinks per week had a lower risk of frailty compared to non-drinkers. Kojima et al. [44]. conducted a meta-analysis and suggested that higher alcohol consumption might be associated with reduced frailty risk, although their study lacked adequate adjustment for confounding factors. Current research generally does not recommend any amount of alcohol consumption, as it can adversely affect health through intoxication, impaired glucose metabolism, inflammation, and is linked to increased mortality from various causes including cardiovascular diseases and cancers [45, 46]. Therefore, public health interventions for frailty should discourage alcohol consumption, and further large-scale studies are needed to clarify the relationship between alcohol and frailty.

BMI cannot accurately reflect the distribution of body composition components such as muscle and fat, and therefore fails to fully capture the adverse health consequences of obesity. Moreover, it is influenced by factors such as age and gender. Recently proposed body measurement indices incorporate multiple data points including height, weight, and waist circumference to comprehensively assess physical health. For instance, Body Roundness Index (BRI) incorporates height and waist circumference to consider weight distribution across different heights, offering advantages in identifying obesity morphology [47]. A Body Shape Index (ABSI) calculates abdominal fat distribution relative to both waist circumference and BMI, providing precise measurements of abdominal versus total body fat relationships [48]. However, these indices require complex calculations and high precision data, limiting their applicability. The calculation of waist-to-hip ratio is relatively simple, but since it does not account for weight, it may exhibit significant variation due to changes in the body type of the person being measured. This study utilizes WWI, proposed in 2018, as an indicator of central obesity and a mediating variable to assess the relationship between healthy lifestyle and frailty. WWI can be easily calculated using weight and waist circumference and reduces reliance on BMI. As an assessment tool for abdominal obesity, WWI has been extensively validated in epidemiological and clinical research [49–51]. Our study found a significant nonlinear correlation between WWI and frailty, which did not change with the adjustment of age and gender. We noted that a healthy lifestyle is associated with a low-quartile WWI. In addition, we found a significant association between five healthy lifestyle factors (non-smoking, healthy weight, healthy diet, sufficient physical activity, and non-sedentary) and WWI, which demonstrates the importance of diet and exercise in controlling central obesity. Based on the above findings, we further conducted a mediating analysis, which proved that obesity assessed by WWI is an important mediator of the association between a healthy lifestyle and frailty. There is growing evidence to show that changes in the position of body fat are associated

with different risks of diseases such as cardiovascular diseases, diabetes, and cancers [52, 53]. WWI is positively correlated with visceral fat and negatively with abdominal muscles, suggesting that WWI may reflect excessive fat storage and decreased muscle mass [54]. Reduced physical activity and increased levels of oxidative stress caused by aging decrease muscle mass [55]. The downregulation of muscle strength and function associated with aging, particularly the decrease in force produced per unit area of skeletal muscle, increases the risk of frailty [56, 57]. Frailty not only changes the total amount of body fat but also redistributes it [58]. An increase in chest and abdominal fat can decrease lung volume and change ventilation patterns, affecting respiratory function in frail patients and increasing the risk of cancer in characteristic areas [59].

Our study has several advantages and limitations. The main advantages are that it uses a large sample size, which enhances statistical power and bolsters the reliability of our findings. This allows for broader generalization of our results to the wider U.S. population. In addition, in our analysis, we adjusted for various pertinent demographic and socioeconomic covariates to ensure a more accurate association between healthy lifestyle, WWI, and frailty. Further, we identified a nonlinear association between WWI and FI, employing threshold effects analysis to provide supplementary evidence. However, the study has some limitations. First, NHANES, as a cross-sectional study, hinders the establishment of causality and is more susceptible to confounding variables. Second, reliance on self-reported data introduces the potential for recall bias, despite prior validation of the questionnaires' reliability. Third, our findings are restricted to the NHANES dataset, which exclusively represents the U.S. population, thereby limiting geographic generalizability. Additionally, due to limitations in the NHANES database, the definitions for some variables, such as alcohol consumption, are not as detailed as desired. Consequently, the transferability of our conclusions to diverse ethnic groups or countries beyond the United States requires further investigation.

Conclusions

Our study found that healthy lifestyle and healthy lifestyle factors were significantly associated with lower frailty prevalence in adults. WWI had a significant nonlinear positive correlation with FI and could be used as a mediator between healthy lifestyle and frailty. These findings highlight the importance of promoting the adoption of a healthy lifestyle as a public health intervention and the potential utility of WWI in assessing frailty.

Abbreviations

BMI	Body Mass Index
CDC	Centers for Disease Control and Prevention
FI	Frailty Index
HEI	Healthy Eating Index
NHANES	National Health and Nutrition Examination Survey
OR	Odds Ratios
USDA	US Department of Agriculture
WWI	Weight-adjusted Waist Index
BRI	Body Roundness Index
ABSI	A Body Shape Index

Supplementary Information

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Supplementary Material 1

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Author contributions

X.T. and Y.Q. conceived the study design and are responsible for the overall content. S.L. analyzed and interpreted the data. S.L., B.C., X.P. and R.L. prepared the manuscript. D.Z. and S.X. edited the manuscript. All authors approved the submitted and final versions.

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Data availability

The National Health and Nutrition Examination Survey (NHANES) data are publicly available at https://www.cdc.gov/nchs/nhanes/.

Declarations

Ethics approval and consent to participate

This study received approval from the ethics review board of the National Center for Health Statistics. Written informed consent was provided by all participants. Furthermore, all methods were performed following relevant guidelines and regulations. Detailed information can be fpund on https://www.cdc.gov/nchs/nhanes/irba98.htm.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

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