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ORIGINAL RESEARCH

Association Between Cardiovascular Health (Life's Crucial 9) and Stress Urinary Incontinence in Women: The Mediating Role of Oxidative Stress Factors (NHANES 2005-2018)

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Objective: Cardiovascular disease and stress urinary incontinence (SUI) may be interconnected. This study aimed to investigate whether indicators of oxidative stress play a moderating role in the relationship between SUI and Life's Crucial 9 (LC9), a cardiovascular health (CVH) index incorporating mental health.

Methods: Data from 5,292 US women aged 20 and older were analyzed using the National Health and Nutrition Examination Survey database from 2005 to 2018. The LC9 score, which was determined by averaging the sum of the eight LE8 component scores and the depression score. To assess the relationship between LC9 and SUI, restricted cubic splines (RCS) analysis and weighted multivariate logistic regression were employed. Additionally, mediation analysis was conducted to evaluate the indirect impact of oxidative stress markers on this relationship.

Results: After adjusting for potential confounders, individuals in the second and highest tertiles of LC9 exhibited significantly higher odds of SUI [odds ratios (OR) for each 1-point increase were 0.817 and 0.765; 95% confidence intervals (CI), 0.673–0.993 and 0.600–0.975, respectively]. Furthermore, RCS results suggested an approximately linear dose-response relationship between LC9 and the prevalence of SUI. Additionally, mediation analysis indicated that oxidative stress biomarkers, specifically bilirubin and uric acid, mediated the relationship between LC9 and SUI, with mediation proportions of 2.22% and 2.64%, respectively ($P < 0.05$).

Conclusion: The present study suggests that higher LC9 scores, which represent ideal CVH, are significantly associated with reduced odds of SUI. Additionally, oxidative stress biomarkers may play a mediating role in this relationship.

Keywords: life's crucial 9, stress urinary incontinence, cardiovascular health, oxidative stress, NHANES

Introduction

Urinary incontinence (UI) is a pervasive condition affecting women globally, causing substantial psychological distress, social isolation, and economic burden.[1] Among its subtypes, stress urinary incontinence (SUI)—characterized by involuntary leakage during exertion—is the most prevalent.[2] Traditionally, SUI has been attributed to local pelvic factors such as childbirth, aging, and pelvic floor trauma. However, emerging epidemiological evidence suggests that SUI is not merely a localized disorder but potentially a manifestation of systemic metabolic and vascular dysfunction.[3,4] Studies have linked SUI to components of metabolic syndrome, including obesity, hyperglycemia, and dyslipidemia, suggesting that poor cardiovascular health (CVH) may accelerate pelvic floor aging and dysfunction.[4]

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To quantify CVH, the American Heart Association (AHA) introduced the "Life's Essential 8" (LE8) framework in 2022, which encompasses four health behaviors (diet, physical activity, nicotine exposure, sleep) and four health factors (BMI, blood lipids, blood glucose, blood pressure).[5] While LE8 is a robust predictor of cardiovascular and chronic disease outcomes, it has a notable limitation: it does not explicitly quantify psychological well-being.[6] This is a critical gap because mental health disorders, particularly depression, share a bidirectional relationship with both cardiovascular disease and urinary incontinence.[7,8] Psychological stress can exacerbate SUI symptoms through neuroendocrine dysregulation and increased urge perception, while SUI itself induces anxiety. To address this, the concept of "Life's Crucial 9" (LC9) has been proposed, integrating mental health metrics (such as depression scores) into the LE8 framework to provide a more holistic assessment of health status.

Despite the biological plausibility linking comprehensive CVH to pelvic health, the association between the novel LC9 metric and SUI remains unexplored. Furthermore, the biological mechanisms underlying this potential connection are not fully understood. Oxidative stress has emerged as a promising mediator. Systemic inflammation and metabolic dysregulation (hallmarks of poor CVH) lead to the accumulation of reactive oxygen species (ROS).[9] Elevated ROS levels can induce apoptosis in urethral sphincter cells and degrade collagen in the pelvic support structures, theoretically linking poor LC9 scores to the pathogenesis of SUI.[10,11]

Therefore, this study aims to bridge these gaps by utilizing data from the National Health and Nutrition Examination Survey (NHANES). We sought to (1) investigate the association between the composite LC9 score and the prevalence of SUI in US women, and (2) explore whether oxidative stress biomarkers (specifically bilirubin and uric acid) mediate this relationship. This study provides the first evidence positioning SUI management within the broader context of holistic cardiovascular and psychological health promotion.

Materials and Methods

Study Population

Through a series of intricate, stratified, multistage, continuous, and nationally representative studies, the health and nutritional status of the civilian noninstitutionalized population in the United States was examined during the NHANES. The NHANES methodology and analytical methods provide detailed information. Through home interviews and blood testing, NHANES collected comprehensive data on various health topics, including medical status, dietary consumption, socioeconomic status, and demographic characteristics.[12] Participants provided written informed consent at the time of enrollment, and the NHANES study protocol received approval from the National Center for Health Statistics Research Ethics Review Board (https://www.cdc.gov/nchs/nhanes/irba98.htm). Since the research was based on publicly accessible, de-identified data, ethical approval and consent were not required.

For our analysis, we utilized seven cycles of the NHANES dataset from 2005 to 2018 that contained complete information. Initially, 19,788 women aged 20 or older who were not pregnant participated during this period. We excluded individuals who did not complete the survey or had incomplete or erroneous data on the LC9 score and stress incontinence questionnaires (n = 5,912 and n = 6,927, respectively). Additionally, we removed participants lacking comprehensive data on variables such as BMI, education, marital status, Poverty Income Ratio (PIR), alcohol consumption, and smoking. Consequently, our final analysis included a total of 5,592 participants (Figure S1).

Measurement of LC9

Four health behaviors—diet, physical activity, nicotine exposure, and sleep duration—along with four health factors—body mass index, non-HDL cholesterol, blood glucose, and blood pressure—and a mental health indicator, the depression scale score, comprise the LC9 scoring system.[13] Table S1 presents the published algorithm used to calculate the LC9 scores for each indicator in the NHANES data. Overall, the LC9 score is determined by calculating the unweighted average of the nine CVH markers, which have scores ranging from 0 to 100.[5] To further investigate the relationship between the LC9 subscales and SUI, we employed the same definitions in this study to evaluate and classify health behaviors, health variables, and depression scores.

To evaluate dietary indicators, the Healthy Eating Index (HEI) 2015[14] was utilized. Table S2 summarizes the components and scoring standards of the HEI-2015. The HEI-2015 score was constructed and calculated using food pattern equivalency data from the United States Department of Agriculture (USDA) and the dietary intake of participants,[15] which was gathered from two 24-hour dietary recalls. The National Cancer Institute's official SAS codes (https://epi.grants.cancer.gov/hei/sas-code.html) were employed to compute HEI-2015 scores using a straightforward HEI scoring system for each individual. Self-report questionnaires were administered to collect data on medication history, physical activity, smoking habits, sleep patterns, and diabetes. The physical examination included measurements of weight, height, and blood pressure. Body Mass Index (BMI) was calculated by dividing weight in kilograms by height in meters squared. Blood samples were collected and sent to a central laboratory for testing of lipids, blood glucose, and glycosylated hemoglobin. Depression scores were derived from the Patient Health Questionnaire-9 (PHQ-9), a validated structured tool for depression screening.[16] Higher PHQ-9 scores indicate greater levels of current depressive symptoms. Depression scores of 100, 75, 50, 25, and 0 corresponded to ranges of 0–4, 5–9, 10–14, 15–19, and 20–27 on the PHQ-9 scale, respectively.

SUI Assessment

The SUI indicator, is based on responses to the Renal Status-Urology Survey. Participants are asked the question, "In the past 12 months, have you ever leaked urine or lost control of your urine, even in small amounts, during activities such as coughing, lifting weights, or exercising?" Those who report experiencing SUI are identified accordingly. Other types of urinary incontinence, are determined based on positive responses to the following questions: "In the past 12 months, have you leaked urine or lost control of even a small amount of urine during activities due to the urge or pressure to urinate, where you couldn't get to the toilet fast enough?" and "In the past 12 months, have you ever leaked urine or lost control, even a small amount, without coughing, lifting weights, exercising, or experiencing the urge to urinate?"[17]

Assessment of Oxidative Stress Markers

The analysis included GGT (U/L), bilirubin (mg/dL), and uric acid (mg/dL) as potential biomarkers related to oxidative stress. These three indicators have well-established roles in reflecting systemic redox status, are widely adopted in routine clinical testing, feature standardized measurement methods, and have been extensively used in population-based studies of cardiovascular and urinary health,[18,19] thereby enhancing the reproducibility and translational relevance of our findings. These biomarkers were measured using the Beckman Coulter UniCel Dx800 instrument (Brea, CA). Gamma-glutamyl transferase activity was determined by an enzyme rate method, while bilirubin concentration was assessed using a timed-endpoint diazo method (Jendrassik–Grof). Similarly, uric acid concentration was measured with a timed-endpoint method. Detailed laboratory procedures are available on the NHANES website.

Covariates

Based on previous studies[20,21] and directed acyclic graph (DAG) (Figure S2), we selected the following potential confounding variables from demographics, examination, laboratory and questionnaire data in our analyses: age (years), race/ethnicity (non-Hispanic white, non-Hispanic black, Mexican American, others), education level (under high school, high school, above high school), poverty income ratio (PIR) (0.00–1.30, 1.31–3.50, >3.51), body mass index (BMI, kg/m^2) (the usual cutoffs are <25, 25–29.9, ≥30, which also applies to Table 1), smoking status [nonsmoking (serum cotinine<0.011 ng/mL), passive smoking (0.011 ng/mL≤serum cotinine<10 ng/mL), active smoking (0.011 ng/mL≤serum cotinine<10 ng/mL)], alcohol intake [non-drinking (0 g/d), low to moderate drinking (0.1 to 27.9 g/d for men and 0.1 to 13.9 g/d for women), heavy drinking (≥28 g/d for men and ≥14 g/d for women)], hypertension (yes, no), diabetes (yes, no), physical activity based on whether participated in vigorous recreational activities or moderate recreational activities (yes, no), total energy intake (kcal/day), and hysterectomy (yes, no, or missing). Hypertension and diabetes are both determined based on self-reported health questionnaires. A vaginal birth count of 0 was defined as having no history of vaginal birth, and a vaginal birth count ≥1 was considered a vaginal birth. A history of macrosomia delivery was defined as having delivered a baby weighing >9 pounds.

Table 1 Demographic Characteristics by Life's Crucial 9 Categories

	Total (n = 5292)	Life's Crucial 9			*P*-value
		Low (n = 1776)	Medium (n = 1763)	High (n = 1753)	
Age, Median (Q1,Q3)	49 (35, 64)	57 (44, 68)	49 (35, 64)	41 (29, 55)	< 0.001
BMI, n (%)					
Normal<25	1655 (31.3)	206 (11.6)	488 (27.7)	961 (54.8)	
Overweight 25–30	1566 (29.6)	436 (24.5)	561 (31.8)	569 (32.5)	
Obese>30	2071 (39.1)	1134 (63.9)	714 (40.5)	223 (12.7)	
Race, n (%)					< 0.001
Non-Hispanic white	2750 (52.0)	859 (48.4)	893 (50.7)	998 (56.9)	
Non-Hispanic black	974 (18.4)	424 (23.9)	349 (19.8)	201 (11.5)	
Mexican American	915 (17.3)	307 (17.2)	309 (17.5)	299 (17.1)	
Others	653 (12.3)	186 (10.5)	212 (12.0)	255 (14.5)	
PIR, n (%)					< 0.001
0.00–1.30	1608 (30.4)	724 (40.8)	514 (29.2)	370 (21.1)	
1.31–3.50	2032 (38.4)	694 (39.0)	707 (40.1)	631 (36.0)	
>3.51	1652 (31.2)	358 (20.2)	542 (30.7)	752 (42.9)	
Education, n (%)					< 0.001
Lower than high school	1316 (24.9)	656 (36.9)	413 (23.4)	247 (14.1)	
High school or equivalent	1235 (23.3)	474 (26.7)	456 (25.9)	305 (17.4)	
College or above	2741 (51.8)	646 (36.4)	894 (50.7)	1201 (68.5)	
Physical activity, n (%)					< 0.001
No	2684 (50.7)	1314 (74.0)	856 (48.6)	514 (29.3)	
Yes	2608 (49.3)	462 (26.0)	907 (51.4)	1239 (70.7)	
Smoking, n (%)					< 0.001
Non-smoking	1280 (24.2)	311 (17.5)	371 (21.0)	598 (34.1)	
Passive smoking	2910 (55.0)	834 (47.0)	1031 (58.5)	1045 (59.6)	
Active smoking	1102 (20.8)	631 (35.5)	361 (20.5)	110 (6.3)	
Alcohol, n (%)					< 0.001
Non-drinking	4283 (80.9)	1548 (87.2)	1424 (80.8)	1311 (74.7)	
Low to moderate drinking	306 (5.8)	59 (3.3)	111 (6.3)	136 (7.8)	
Heavy drinking	703 (13.3)	169 (9.5)	228 (12.9)	306 (17.5)	
Hypertension, n (%)					< 0.001
No	3435 (64.9)	791 (44.5)	1151 (65.3)	1493 (85.2)	
Yes	1857 (35.1)	985 (55.5)	612 (34.7)	260 (14.8)	
Diabetes, n (%)					< 0.001
No	4699 (88.8)	1339 (75.4)	1630 (92.5)	1730 (98.7)	
Yes	593 (11.2)	437 (24.6)	133 (7.5)	23 (1.3)	
Vaginal deliveries, n (%)					< 0.001
No	564 (10.6)	191 (10.8)	179 (10.2)	194 (11.0)	
Yes	2691 (50.9)	1006 (56.6)	902 (51.3)	783 (44.7)	
Missing	2037 (38.5)	579 (32.6)	682 (38.7)	776 (44.3)	
Cesarean deliveries, n (%)					< 0.001
No	1009 (19.1)	379 (21.3)	347 (19.7)	283 (16.1)	
Yes	706 (13.3)	272 (15.4)	206 (11.7)	228 (13.1)	
Missing	3577 (67.6)	1125 (63.3)	1210 (68.6)	1242 (70.8)	
Macrosomia, n (%)					< 0.001
No	2527 (47.8)	917 (51.6)	839 (47.6)	771 (44.0)	
Yes	555 (10.5)	227 (12.8)	178 (10.1)	150 (8.5)	
Missing	2210 (41.7)	632 (35.6)	746 (42.3)	832 (47.5)	
Hysterectomy, n (%)					< 0.001
No	2886 (54.5)	858 (48.3)	925 (52.5)	1103 (62.9)	
Yes	921 (17.4)	438 (24.7)	302 (17.1)	181 (10.3)	
Missing	1485 (28.1)	480 (27.0)	536 (30.4)	469 (26.8)	

Notes: The continuous variables were analyzed by Wilcoxon test, expressed by the median (IQR); the chi-square test was used to analyze the categorical variables, expressed by the column percentage. A level of two-sided $P < 0.05$ was considered statistically significant.
Abbreviations: PIR, poverty income ratio; BMI, body mass index.

Statistical Analysis

All statistical analyses accounted for the complex, multi-stage probability sampling design of NHANES. This was implemented using the R survey package (version 4.2.1). A survey design object was created incorporating the interview/examination sample weights (WTMEC2YR), strata (SDMVSTRA), and primary sampling units (SDMVPSU). To generate appropriate weights for the combined survey periods, the two-year examination weight for each NHANES cycle was divided by two.For this study, during data processing and analysis, we assessed continuous variables for normal distribution, and the results indicated that all continuous variables were non-normally distributed. Therefore, we used the median (interquartile range, IQR) for non-normally distributed continuous variables and frequency (weighted percentage) for categorical variables. For categorical and non-normally distributed continuous variables, the chi-square test and the Kruskal–Wallis test were used to assess differences in the characteristics of the variables within each LC9 group (tertiles), respectively. The normality test revealed that the age at menopause and reproductive lifespan were skewed; therefore, they were ln-transformed to achieve a distribution that resembled a normal distribution.

The multivariable logistic regression model was utilized to examine the relationship between LC9 score and its subcomponent scores and prevalence of SUI. Multivariable logistic regression analyses were performed on all variables found to have a statistically significant association (two-tailed, $P<0.05$) in the univariable analyses. Both categorical and continuous models were used. The lowest tertile of the LC9 and its subcomponent scores was utilized as the reference group in the categorical mode, where the LC9 and its subcomponent scores was split into tertiles. Utilizing ordered integer values, trend tests were conducted in the linear regression models across increasing LC9 tertile and and its subcomponent scores categories. No covariates were adjusted in Model 1. Model 2 was adjusted for age, race, PIR, education level, smoking status, alcohol intake, hypertension, diabetes, physical activity, vaginal deliveries, cesarean deliveries, macrosomia, and hysterectomy. And all regressions included survey weights. Furthermore, the weighted restricted cubic spline model (RCS) with three knots at the 5th, 50th, and 95th percentiles of the distribution were used to investigate any potential dose-response relationship between LC9 score and its subcomponent scores and odds of SUI.

The mediating role of oxidative stress biomarkers in the relationship between LC9 score and SUI prevalence was further assessed by weighted mediation analysis modeling. In the mediation analysis, two models were constructed: a mediation model referred to the GLM used to assess the relationship between LC9 score (exposure variable) and oxidative stress biomarkers (mediator variable); and the outcome model referred to the GLM and logistic regression model, including exposure and mediator variables, to assess their effects on the prevalence of SUI (outcome variable), respectively. The direct effect (DE) represents the effect of LC9 score on the prevalence of SUI, whereas the indirect effect (IE) represents the effect of oxidative stress biomarker-mediated LC9 score on the prevalence of SUI. The proportion of mediated effects was calculated by dividing the indirect effect (IE) by the total effect (TE).

To ensure robustness, several sensitivity analyses were conducted. First, the relationship between LC9 scores and reproductive life span as well as miscarriage rate was investigated using multiple linear regression modeling, excluding LC9 scores less than mean - 3SD and greater than mean + 3SD. Second, subgroup analyses were performed to examine whether the effects of LC9 scores and reproductive life expectancy as well as miscarriage rate could be modified by covariates through regression models that included subgroup interaction terms in separate models. Wald tests were used to estimate *P* values for interactions. Thirdly, to examine whether the observed association between LC9 and SUI differed by menopausal and parity status, we performed a prespecified subgroup analysis. Female participants were stratified into different groups based on through a self-reported reproductive health questionnaire.[22] All regression and mediation models were fitted separately within each subgroup, while maintaining the same covariate adjustment strategy as in the primary analysis. Furthmore, all covariates were used to perform 1:1 propensity score matching (PSM). Weighted logistic regression was then reapplied to the matched sample to reassess the association between LC9 and SUI. Finally, the relative significance of the impacts of several factors on odds of SUI was predicted using the eXtreme Gradient Boosting (XGBoost) machine learning algorithm model. All statistical analysis was conducted by using R software (version 4.2.1). Two-sided *P* values < 0.05 was considered statistically significant difference.

Results

Baseline Characteristics of Study Participants

The postmenopausal participants' average age and BMI were 49.71 ± 17.56 years and 29.24 ± 7.28 kg/m^2, respectively. Among all participants, 43.27% were found to exhibit SUI. More than half (52.0%) of these participants were non-Hispanic White (Table 1). The mean (standard deviation) of the LC9 score was 68.83 (14.69). Compared with the other groups, the highest LC9 score tertile group often consisted of younger, non-Hispanic white individuals with higher BMI and total calorie consumption, as well as higher levels of education and economic status. The LC9 score of participants with college or above and never-smokers were higher than that of their counterparts. As LC9 score increased, the proportion of individuals who were also physically active, the proportion of non-hypertension and non-diabetes also increased ($P < 0.05$). Moreover, patients with SUI usually had a lower percentage of macrosomia compared with participants without SUI (8.6 vs 12.8).

Association of CDAI with Reproductive Lifespan

To evaluate the relationship between the LC9 score and the risk of SUI in US women, multivariable logistic regression analyses were conducted (Table 2). The preliminary analysis revealed a negative correlation between the risk of SUI and each unit increase in the LC9 score when the score was treated as a continuous variable (odds ratio [OR] = 0.976; 95% confidence interval [CI]:0.972–0.980). After within the in logistic regression, it was determined that a 1-point increase in the LC9 score corresponded to the odds of SUI was 0.988 (95% CI: 0.979–0.997). For the categorical variable, the risk of SUI was significantly lower in the high LC9 group (OR: 0.765, 95% CI: 0.600–0.975) compared with that to LC9 group. As for the specific components of LC9, the highest tertile of health factor score was linked to lower odds of SUI prevalence when compared to the lowest tertile of health factor score [OR = 0.479 (0.400, 0.574), $P < 0.001$]. Health factor scores and the incidence of SUI also showed comparable exhibited similar the high and low groups at preliminary

Table 2 Multivariable Regression Analysis of Associations Between Life's Crucial 9 and Stress Urinary Incontinence (SUI), National Health and Nutrition Examination Survey, 2005–2018

Variable	Univariable		Multivariable	
	OR (95% CI)	*P*-value	OR (95% CI)	*P*-value
Life's Crucial 9[a]				
Continuous variable	0.976 (0.972, 0.980)	<0.001	0.988 (0.979, 0.997)	0.013
Categorical variable				
Tertile 1	Ref		Ref	
Tertile 2	0.652 (0.559, 0.760)	<0.001	0.817 (0.673, 0.993)	0.043
Tertile 3	0.470 (0.408, 0.542)	<0.001	0.765 (0.600, 0.975)	0.032
Health behavior score[b]				
Low	Ref		Ref	
Moderate	0.911 (0.763, 1.087)	0.305	0.864 (0.724, 1.031)	0.118
High	0.896 (0.764, 1.052)	0.187	0.905 (0.758, 1.080)	0.279
Health factor score[c]				
Low	Ref		Ref	
Moderate	0.689 (0.592, 0.804)	<0.001	0.748 (0.633, 0.884)	0.002
High	0.378 (0.318, 0.449)	<0.001	0.479 (0.400, 0.574)	<0.001
PHQ-9 score	1.061 (1.043, 1.079)	<0.001	1.066 (1.043, 1.089)	<0.001

Notes: [a]Model was adjusted for age, BMI, race, PIR, education level, smoking status, alcohol intake, hypertension, diabetes, physical activity, vaginal deliveries, cesarean deliveries, macrosomia, and hysterectomy. [b]Model was adjusted for age, BMI, race, PIR, education level, alcohol intake, hypertension, diabetes, vaginal deliveries, cesarean deliveries, macrosomia, and hysterectomy. [c]Model was adjusted for age, race, PIR, education level, smoking status, alcohol intake, physical activity, vaginal deliveries, cesarean deliveries, macrosomia, and hysterectomy.

Abbreviations: OR, odds ratio; CI, confidence interval; PHQ-9, Patient Health Questionnaire-9.

in the although no significant significance was differences were the adjusted model. Meanwhile, in the adjusted model, the OR for each 1-point increase in PHQ-9 in the was 1.066 (95% CI: 1.043–1.089), suggesting a indicating association with the risk of SUI.

Following the adjustment for potential confounders, a significant linear relationship (P for overall < 0.001, P for nonlinearity = 0.632) was identified between LC9 score and odds of SUI in a weighted restricted cubic spline regression. The RCS results suggested a negative correlation between the LC9 score and its components, showing that the OR of SUI decreased with increasing scores on LC9, health behaviors, and their health factors (Figures 1 and S3). Notably, the nonlinear relationships between PHQ-9 score and SUI were statistically significant (P for nonlinearity < 0.05), as depicted in Figure S3, even after controlling for numerous potential confounders.

Mediation Analyses

To investigate the mediating role of oxidative stress indicators, we conducted a weighted mediation analysis. The relationship between the LC9 score and stress urinary incontinence (SUI) is mediated by oxidative stress indicators, as illustrated in Figure 2. Specifically, the relationship between the LC9 score and SUI was significantly mediated by both bilirubin and uric acid, which accounted for 2.22% and 2.64% of the association, respectively (P < 0.05). However, no significant mediating effect of GGT in the association between LC9 and stress urinary incontinence was found (P = 0.36) (Figure 2).

Sensitivity Analyses

The robustness of the study's findings was confirmed through several sensitivity analyses. First, subgroup analysis (Table S3) demonstrated a strong correlation between SUI and the LC9 score across various demographic categories. The reduced probabilities of SUI were not significantly influenced by the stratification variables (P for interaction > 0.05) except for vaginal deliveries, cesarean deliveries, and macrosomia. The OR remained consistent across all stratifications by BMI, race, education, PIR, physical activity, smoking status, alcohol consumption, diabetes, hypertension, and

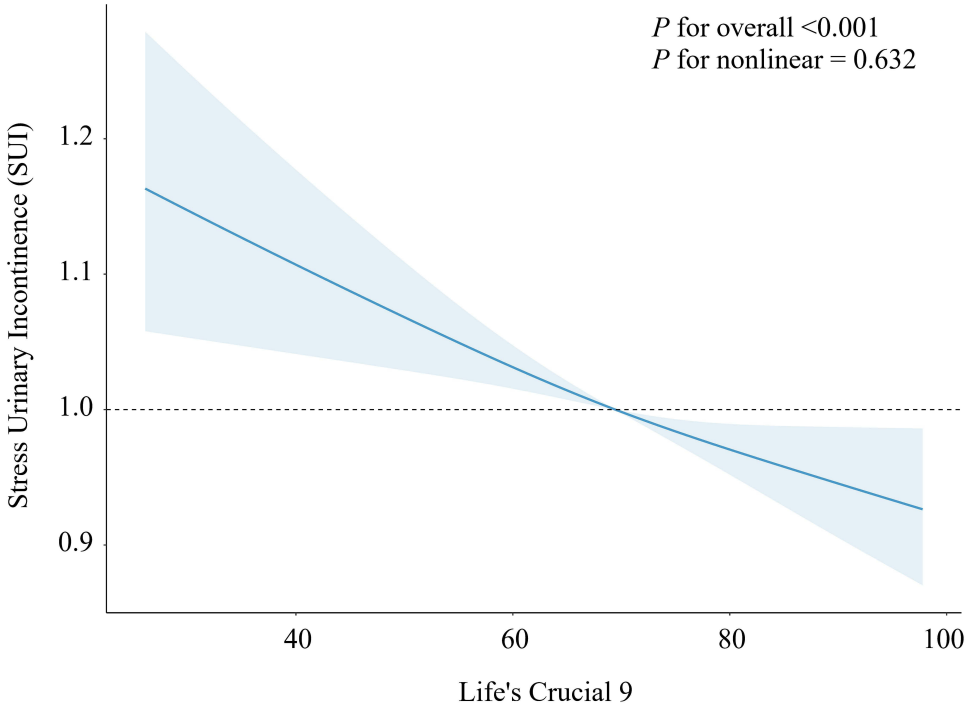

Figure 1 Relationship between "Life's Crucial 9" and "Stress Urinary Incontinence (SUI)." The x-axis represents "Life's Crucial 9" (0 to 100), and the y-axis represents SUI values (0.0 to 2.0). A fitted line shows a decrease in SUI values as "Life's Crucial 9" increases, with the shaded area representing the confidence interval. Model was adjusted for age, BMI, race, PIR, education level, smoking status, alcohol intake, hypertension, diabetes, physical activity, vaginal deliveries, cesarean deliveries, macrosomia, and hysterectomy.

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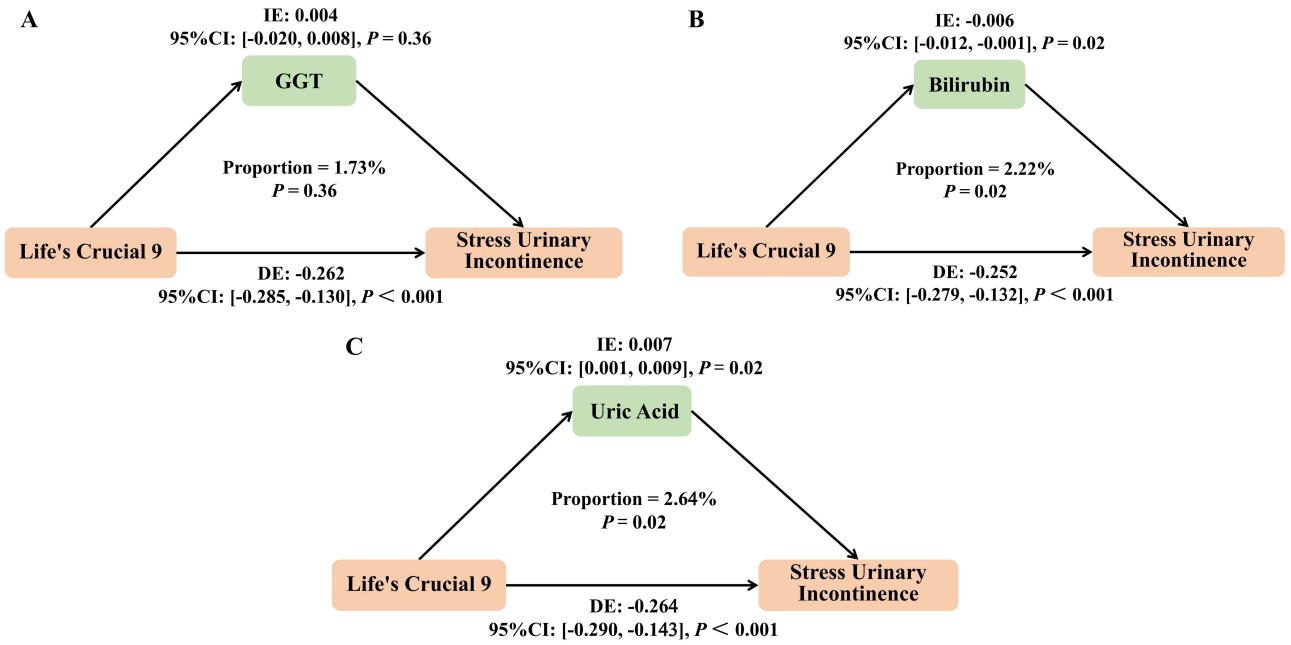

Figure 2 Estimated proportion of the association between Life's Crucial 9 and stress urinary incontinence mediated by oxidative stress factor. (**A**) The mediating effect of GGT in stress urinary incontinence. (**B**) The mediating effect of bilirubin in stress urinary incontinence. (**C**) The mediating effect of uric acid in stress urinary incontinence. Model was adjusted for age, BMI, race, PIR, education level, smoking status, alcohol intake, hypertension, diabetes, physical activity, vaginal deliveries, cesarean deliveries, macrosomia, and hysterectomy.

hysterectomy. Second, weighted multivariate linear regression was employed after eliminating extreme data and the LC9 score. All results indicated a negative association between the LC9 score and SUI in both fully adjusted and non-adjusted models, which aligns with the previously discussed findings (Table S4–5 and S4). Thirdly, the inverse association between LC9 score and odds of SUI was consistent across menopausal status. In subgroup analyses, the direction and magnitude of the association remained similar in both premenopausal and postmenopausal women (Table S6), supporting the robustness of the primary findings. In a pre-specified subgroup analysis stratified by parity (nulliparous vs parous), the inverse association between LC9 score and odds of SUI was significantly modified by parity status (*P* for interaction = 0.005). While a protective association was observed in both groups, the effect was more pronounced in nulliparous women compared to parous women (Table S6). After 1:1 PSM, 162 participants with epilepsy and 162 without were included. The baseline features were better balanced across the two groups (all absolute standardized mean differences (ASMD) < 0.1), as shown in Figure S5. Weighted logistic regression conducted in the PSM cohort still demonstrated significant effects for LC9 (OR (95% CI): 0.989 (0.984, 0.993)) (Table S7).

Finally, to assess the efficacy of the LC9 score in predicting the odds of SUI, we utilized the XGBoost machine learning model to determine the relative importance of selected factors associated with SUI. The three most significant factors influencing age at menopause were identified as age, LC9 score, and race, based on the contributions of each variable as determined by the XGBoost model (Figure 3A). The predictive efficacy of the LC9 score on the odds of SUI was also significant (SHAP values = 0.079; Figure 3B). In conclusion, a high LC9 score had a substantial positive impact on reducing the prevalence of SUI.

Discussion

This study is the first to investigate the relationship between SUI and CVH, as measured by LC9 scores, in a nationally representative sample of American women. The results reveal a strong association, indicating that a lower odds of SUI is linked to higher LC9 scores. Specifically, an OR of 0.988 for SUI is associated with each one-point increase in the LC9 score. The role of oxidative stress indicators as mediators in this association is further supported by the mediation analysis. These findings underscore the importance of maintaining cardiovascular health as an effective strategy for slowing the progression of pelvic floor dysfunction.

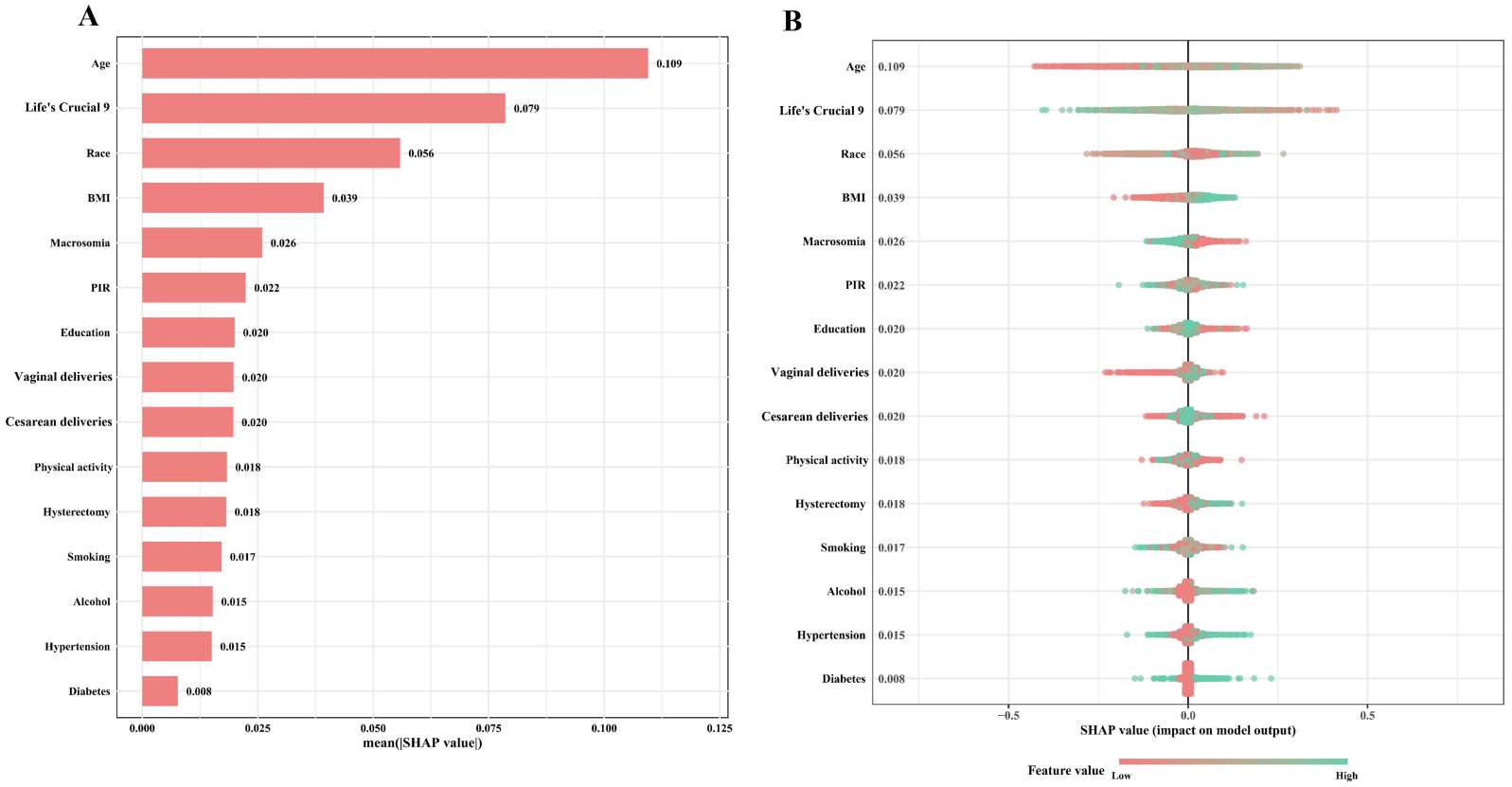

Figure 3 Feature importance analysis using SHAP (SHapley Additive exPlanations) values. (**A**) Bar plot showing the mean absolute SHAP values for each feature, indicating their overall importance in predicting the outcome. Features are ranked in descending order of importance, with Age and Life's Crucial 9 contributing the most to the model output. (**B**) SHAP summary plot illustrating the distribution of SHAP values for individual features. Each point represents a single prediction, colored by the feature value (low to high). Features with higher SHAP value variability have a more significant impact on the model output. Features such as Age and Life's Crucial 9 exhibit the greatest influence on model predictions. Model was adjusted for age, BMI, race, PIR, education level, smoking status, alcohol intake, hypertension, diabetes, physical activity, vaginal deliveries, cesarean deliveries, macrosomia, and hysterectomy.

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This study is the first to investigate the association between CVH as measured by the LC9 index, and SUI among US women who participated in the NHANES from 2005 to 2018. Previous research has suggested that a diet high in fat and sugar may be a significant risk factor for SUI.[23,24] Additionally, women who engaged in high-intensity exercise at the gym exhibited a higher prevalence of urinary incontinence symptoms compared to those who did not exercise.[25] A cross-sectional study involving 5,013 women found a strong correlation between SUI and smoking, with a prevalence of 18.92% among smokers and 8.39% among non-smokers.[26] The recommended sleep duration of 6–8 hours per night was linked to a lower incidence of urge incontinence, while sleep duration was not significantly associated with SUI.[27] Furthermore, several studies have demonstrated a positive correlation between women's BMI and SUI.[28,29] Researchers compared 193 participants with and without stressful SUI and discovered that those with SUI had higher blood glucose and serum triglyceride levels.[4] The incidence and severity of urinary incontinence in women with type 2 diabetes were shown to correlate with higher levels of insulin resistance.[30] The results of our study align with findings from a study based on NHANES data from 2005 to 2018, which identified a nonlinear relationship between urinary incontinence and Patient Health Questionnaire (PHQ-9) scores (nonlinear $P < 0.001$),[31] indicating a 7% increase in risk for every 1-point increase in PHQ-9 scores. This suggests that mental health is significantly associated with stress urinary incontinence.

Our study suggests that adherence to the American Heart Association's LC9 cardiovascular health index may be associated with a reduced prevalence of SUI in women. For participants in the highest tertile CVH group, the odds of SUI were reduced by 23.5% compared to the lowest tertile CVH group. These findings have significant clinical implications, highlighting the relationship between cardiovascular health and SUI and probably suggesting a shared pathophysiology. Furthermore, lifestyle modifications—such as smoking cessation, maintaining a healthy weight, regulating blood glucose levels, and following a low-fat diet—have been shown to positively impact cardiovascular health and may also benefit urinary health. Additionally, mental health indicators, newly incorporated into the LC9, are recognized as crucial for energy renewal and cellular recovery. Previous evidence has shown that depression of any severity is associated with stress urinary incontinence (SUI) in women.[31,32] Depression has been linked to the accelerated degradation of the extracellular matrix in pelvic floor muscles through mechanisms that include inducing DNA damage and chronic inflammation. Therefore, including mental health indicators in the LC9 may provide a more comprehensive assessment of the relationship between mental health and pelvic floor dysfunction in women.

There is still much to learn about the processes underlying CVH and SUI. Oxidative stress, a significant indicator of aging that increases susceptibility to age-related illnesses, is one potential contributing factor.[33] Furthermore, mitochondrial damage resulting from oxidative stress may enhance the production of ROS.[33] Mitochondrial dysfunction is recognized as one of the primary mechanisms leading to pelvic floor dysfunction.[33] According to a growing body of research, oxidative stress levels in the body can be reduced by improving cardiovascular risk factors, such as maintaining a healthy diet, quitting smoking, ensuring adequate sleep, and managing blood pressure, blood glucose, and body mass index.[34,35] Notably, exercising muscles can increase ROS production, which induces oxidative stress in various tissues.[36] However, the impact of exercise-induced increases in ROS production on overall health remains unclear. Nevertheless, moderate exercise has been shown to help alleviate SUI, indicating that there are additional ways in which exercise influences this condition.[37,38] In this study, we explored the relationship between oxidative stress indicators and the integration of CVH-related variables (LC9). We found a strong negative correlation between LC9 scores and uric acid levels, a positive correlation with bilirubin, and a negative correlation with oxidative stress markers. To further elucidate the mechanism linking CVH and SUI, we conducted a mediation analysis based on these findings and confirmed that the two oxidative stress indicators (including bilirubin and uric acid) mediated the relationship between LC9 scores and SUI.

Based on a nationally representative sample of the US population, the current study identified a negative relationship between women's stress urinary incontinence and LC9 scores. It also explored the potential mediating role of biomarkers for oxidative stress in this context. Rather than stemming from a single cause, stress incontinence is likely the result of a confluence of several CVH-related factors. Additionally, we conducted several sensitivity analyses to enhance the validity of our conclusions. However, this study has several limitations. First, we were unable to establish a causal association between LC9 scores, oxidative stress biomarkers, and stress urinary incontinence due to the cross-sectional design of the NHANES data, which restricted our evaluation of the nine CVH measures to baseline measurements. To corroborate our findings, future prospective cohort studies are necessary. Second, the use of self-reported questionnaires for assessing measures of depression, physical activity, nicotine

exposure, sleep quality, and dietary intake may introduce bias due to potential recall issues. Thirdly,mediating analysis only indicates that oxidative stress markers may statistically mediate the association, and mechanistic research is still needed to prove the biological causal pathways. Meanwhile, subsequent studies will also note that other confounding factors (such as age and hormonal status) may simultaneously affect oxidative stress, CVH and SUI. Finally, caution should be exercised when generalizing our findings to other populations, as our study relied on the US NHANES database.

Conclusions

In this cross-sectional study, higher LC9 scores were associated with lower SUI prevalence among women. However, this association was markedly attenuated after age adjustment, reflecting the age-driven nature of both CVH and pelvic floor health. Our findings suggest a linear relationship, with no robust evidence of nonlinearity. Exploratory mediation analysis indicates that oxidative stress may partially underlie these findings, offering a biological hypothesis for future study. Given NHANES' inherent limitations, these results represent cross-sectional associations rather than causal evidence. Longitudinal research is necessary to determine if optimizing CVH can effectively delay SUI onset.

Data Sharing Statement

The data supporting the findings of this study are available from the corresponding author upon reasonable request (E-mail: xiaoyanshu11163@163.com). Additionally, the survey data used in this study are publicly accessible worldwide via the official website of the National Health and Nutrition Examination Survey (NHANES): https://www.cdc.gov/nchs/nhanes/.

Ethics Approval and Consent to Participate

The study protocol (Protocol Number: Protocol #2005–06, Protocol #98-12) was approved by the NCHS Research Ethics Review Board (ERB) and all participants provided written informed consent prior to participation.

Based on Item 1 and Item 2 of Article 32 of the Measures for Ethical Review of Life Science and Medical Research Involving Human Subjects, dated February 18, 2023, China, our study is exempt from additional ethical approval.

The relevant legislation details are as follows:

Article 32: Research involving human data or biological samples, where no harm is caused to individuals and no sensitive personal information or commercial interests are involved, may be exempt from ethical review. This is to reduce unnecessary burdens on researchers and to facilitate the progress of life science and medical research involving humans.

(1) Research using publicly available data that has been legally obtained, or data generated through observation without interference with public behavior.
(2) Research using anonymized data.

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Disclosure

Ying Li and Haiyan Huang are co-first authors for this study. The authors declare that they have no conflict of interest.

References

1. Abrams P, Cardozo L, Fall M, et al. The standardisation of terminology in lower urinary tract function: report from the standardisation subcommittee of the international continence society. *Urology*. 2003;61(1):37–49. doi:10.1016/S0090-4295(02)02243-4
2. Luber KM. The definition, prevalence, and risk factors for stress urinary incontinence. *Rev Urol*. 2004;6(Suppl 3):S3–9.
3. Huang H, Han X, Liu Q, Xue J, Yu Z, Miao S. Associations between metabolic syndrome and female stress urinary incontinence: a meta-analysis. *Int Urogynecol J*. 2022;33(8):2073–2079. doi:10.1007/s00192-021-05025-0
4. Ströher RLM, Sartori MGF, Takano CC, de Araújo MP, Girão M. Metabolic syndrome in women with and without stress urinary incontinence. *Int Urogynecol J*. 2020;31(1):173–179. doi:10.1007/s00192-019-03880-6
5. Lloyd-Jones DM, Allen NB, Anderson CAM, et al. Life's essential 8: updating and Enhancing the American Heart Association's construct of cardiovascular health: a presidential advisory from the American Heart Association. *Circulation*. 2022;146(5):e18–e43. doi:10.1161/CIR.0000000000001078

6. Levine GN, Cohen BE, Commodore-Mensah Y, et al. Psychological health, well-being, and the mind-heart-body connection: a scientific statement from the American Heart Association. *Circulation*. 2021;143(10):e763–e783. doi:10.1161/CIR.0000000000000947
7. Melville JL, Walker E, Katon W, Lentz G, Miller J, Fenner D. Prevalence of comorbid psychiatric illness and its impact on symptom perception, quality of life, and functional status in women with urinary incontinence. *Am J Obstet Gynecol*. 2002;187(1):80–87. doi:10.1067/mob.2002.124839
8. Mohamed F, Jeram M, Coomarasamy C, Lauti M, Wilson D, MacCormick AD. Does bariatric surgery improve faecal incontinence? A systematic review and meta-analysis. *Obes Surg*. 2021;31(7):2942–2953. doi:10.1007/s11695-021-05360-7
9. Bungau AF, Radu AF, Bungau SG, Vesa CM, Tit DM, Endres LM. Oxidative stress and metabolic syndrome in acne vulgaris: pathogenetic connections and potential role of dietary supplements and phytochemicals. *Biomed Pharmacother*. 2023;164:115003. doi:10.1016/j.biopha.2023.115003
10. Peters B, Powers SA, Burleson LK, et al. Preclinical female model of urogenital dysfunction and pathophysiological changes after pelvic radiation therapy. *Cureus*. 2024;16(8):e66374. doi:10.7759/cureus.66374
11. Chen WH, Jiang YH, Kuo HC. Urinary oxidative stress biomarkers in the diagnosis of detrusor overactivity in female patients with stress urinary incontinence. *Biomedicines*. 2023;11(2). doi:10.3390/biomedicines11020357
12. Wu LD, Kong CH, Shi Y, Zhang JX, Chen SL. Associations between novel anthropometric measures and the prevalence of hypertension among 45,853 adults: a cross-sectional study. *Front Cardiovasc Med*. 2022;9:1050654. doi:10.3389/fcvm.2022.1050654
13. Ge J, Peng W, Lu J. Predictive value of life's crucial 9 for cardiovascular and all-cause mortality: a prospective cohort study from the NHANES 2007 to 2018. *J Am Heart Assoc*. 2024;13(20):e036669. doi:10.1161/JAHA.124.036669
14. Krebs-Smith SM, Pannucci TE, Subar AF, et al. Update of the healthy eating index: HEI-2015. *J Acad Nutr Diet*. 2018;118(9):1591–1602. doi:10.1016/j.jand.2018.05.021
15. Yi J, Wang L, Guo X, Ren X. Association of life's essential 8 with all-cause and cardiovascular mortality among US adults: a prospective cohort study from the NHANES 2005-2014. *Nutr Metab Cardiovasc Dis*. 2023;33(6):1134–1143. doi:10.1016/j.numecd.2023.01.021
16. Kroenke K, Spitzer RL, Williams JB. The PHQ-9: validity of a brief depression severity measure. *J Gen Intern Med*. 2001;16(9):606–613. doi:10.1046/j.1525-1497.2001.016009606.x
17. Kim MM, Kreydin EI. The association of serum testosterone levels and urinary incontinence in women. *J Urol*. 2018;199(2):522–527. doi:10.1016/j.juro.2017.08.093
18. Liu W, Wang J, Wang M, et al. Oxidative stress factors mediate the association between life's essential 8 and accelerated phenotypic aging: NHANES 2005-2018. *J Gerontol a Biol Sci Med Sci*. 2024;79(1). doi:10.1093/gerona/glad240
19. Qin S, Yang J, Wang Z, et al. Life's Crucial 9 score and chronic kidney disease: insights from NHANES 2005-2018 and the mediating role of systemic inflammation and oxidative stress. *Front Med*. 2025;12:1605931. doi:10.3389/fmed.2025.1605931
20. Xu M, Zhou H, Pan Y, Xu Z, Liu X. Serum albumin levels and stress urinary incontinence in females: a retrospective study based on NHANES 2007-2016. *Heliyon*. 2023;9(11):e21757. doi:10.1016/j.heliyon.2023.e21757
21. Zhang Z, Wang P, Cui G, Li H. Higher HEI-2015 score is associated with reduced risk of fecal incontinence: insights from a large cross-sectional study. *BMC Public Health*. 2024;24(1):3221. doi:10.1186/s12889-024-20729-w
22. Tian J, Huang Y, Xiao Z, et al. The association between the uric acid to high-density lipoprotein cholesterol ratio (UHR) index and obesity in postmenopausal women: a cross-sectional analysis based on the NHANES. *Lipids Health Dis*. 2025;24(1):277. doi:10.1186/s12944-025-02715-2
23. Dallosso H, Matthews R, McGrother C, Donaldson M. Diet as a risk factor for the development of stress urinary incontinence: a longitudinal study in women. *Eur J Clin Nutr*. 2004;58(6):920–926. doi:10.1038/sj.ejcn.1601913
24. Yuan Y, Huang Y, Huang H, Zeng S, Hu Z. Association between added sugar intake and urinary incontinence in females: a cross-sectional population-based study. *Int Urogynecol J*. 2024;35(6):1201–1210. doi:10.1007/s00192-024-05794-4
25. Sun C, Duan Z. Joint effect of physical activity and sedentary behavior with the female urinary incontinence: an analysis of NHANES 2011-2016. *Urol Int*. 2024;108(4):349–358. doi:10.1159/000538339
26. Fozzatti C, Riccetto C, Herrmann V, et al. Prevalence study of stress urinary incontinence in women who perform high-impact exercises. *Int Urogynecol J*. 2012;23(12):1687–1691. doi:10.1007/s00192-012-1786-z
27. Di X, Chen J, Wang M, Liao B. Association between sleep duration and urinary incontinence in female adults: a cross-sectional study in national health and nutrition examination survey 2007-2018. *Urology*. 2023;181:48–54. doi:10.1016/j.urology.2023.08.019
28. Ganz M, Alessandro C, Jacobs M, et al. The role of body mass index and waist circumference in gender-specific risk factors for stress urinary incontinence: a cross-sectional study. *Cureus*. 2023;15(5):e38917.
29. Shang X, Fu Y, Jin X, et al. Association of overweight, obesity and risk of urinary incontinence in middle-aged and older women: a meta epidemiology study. *Front Endocrinol*. 2023;14:1220551. doi:10.3389/fendo.2023.1220551
30. Li S, Zou J, Wang Z, Wang M, Yuan Y, Lv H. Correlation between insulin resistance and urinary incontinence in female patients with type 2 diabetes mellitus. *Int Urogynecol J*. 2024;35(2):431–440. doi:10.1007/s00192-023-05715-x
31. Pan T, He T, Yuan H, et al. Depression of any severity was associated with stress urinary incontinence in females: a retrospective study based on NHANES 2005-2018. *Urology*. 2025;198:17–25. doi:10.1016/j.urology.2024.11.057
32. Choi EP, Lam CL, Chin WY. Mental health mediating the relationship between symptom severity and health-related quality of life in patients with lower urinary tract symptoms. *Low Urin Tract Symptoms*. 2016;8(3):141–149. doi:10.1111/luts.12086
33. Liu C, Wang Y, Li Y, Tang J, Hong S, Hong L. Dimethyl fumarate ameliorates stress urinary incontinence by reversing ECM remodeling via the Nrf2-TGF-β1/Smad3 pathway in mice. *Int Urogynecol J*. 2022;33(5):1231–1242. doi:10.1007/s00192-021-05061-w
34. Sharma V, Mehdi MM. Oxidative stress, inflammation and hormesis: the role of dietary and lifestyle modifications on aging. *Neurochem Int*. 2023;164:105490. doi:10.1016/j.neuint.2023.105490
35. Peluso I, Palmery M, Yarla NS, Perry G, Kamal MA. From oxidative stress to ageing via lifestyle, nutraceuticals, polypharmacy, and neuropsychological factors. *Oxid Med Cell Longev*. 2018;2018(1):6352689. doi:10.1155/2018/6352689
36. Boccatonda A, Tripaldi R, Davì G, Santilli F. Oxidative stress modulation through habitual physical activity. *Curr Pharm Des*. 2016;22(24):3648–3680. doi:10.2174/1381612822666160413123806
37. Pingitore A, Lima GP, Mastorci F, Quinones A, Iervasi G, Vassalle C. Exercise and oxidative stress: potential effects of antioxidant dietary strategies in sports. *Nutrition*. 2015;31(7–8):916–922. doi:10.1016/j.nut.2015.02.005
38. García-Giménez JL, Cánovas-Cervera I, Pallardó FV. Oxidative stress and metabolism meet epigenetic modulation in physical exercise. *Free Radic Biol Med*. 2024;213:123–137. doi:10.1016/j.freeradbiomed.2024.01.008