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Association between frailty with kidney stones disease among adults aged 20 years and older population: a cross-sectional study of NHANES 2007–2020

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Abstract

Purpose Kidney stones (KS) disease is a growing global health concern, increasing prevalence. Its well-established associations with metabolic disorders such as diabetes and hypertension, but the relationship between frailty and KS remains underexplored. This study aims to investigate the association between KS and frailty among adults aged 20 years and older population.

Methods This study investigates the relationship between frailty and KS prevalence using data from the National Health and Nutrition Examination Survey (NHANES) from 2007 to 2020. Frailty was assessed using the Frailty Index (FI), a continuous variable based on 49 health deficits, and categorized into robust, pre-frail, and frail states. Weighted logistic regression and restricted cubic splines (RCS) were used to assess the association between KS and frailty.

Results A total of 28,113 people were included in the study, and the overall prevalence of KS occurrence was 9.576%. The FI in the KS group was higher than that in the no KS group [0.142(0.094–0.216) vs 0.112(0.073–0.172), $p < 0.0001$]. Furthermore, the rate of frail status (17.691% vs 9.791%, $p < 0.0001$) and pre-frail status (54.267% vs 46.929%, $p < 0.0001$) in the KS group were higher than that in the no KS group. Multivariate logistic regression models revealed a significant positive association between frailty and KS prevalence, with frail individuals showing a 1.731-fold increased likelihood compared to robust individuals (95% CI 1.406–2.131, $p < 0.0001$). A nonlinear relationship was observed between the FI and KS occurrence, with likelihood increasing as frailty levels rose. Subgroup analyses indicated that frailty had the greatest impact on KS likelihood in individuals under 60 years, of normal weight, and without hypertension.

Conclusions In adults in the United States, increased frailty is strongly associated with a higher likelihood of developing KS. Early identification and targeted management of frailty could play a crucial role in reducing the prevalence and recurrence of KS.

Keywords Frailty index, Frailty status, Kidney stones, NHANES, Cross-sectional analysis

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Introduction

Kidney stone (KS) disease is a prevalent and serious urological condition affecting human health worldwide. In recent years, the prevalence of KS has risen significantly. The prevalence of KS has increased from 3.2% in the 1980s to 9.6% in the current decade in America [1, 2]. KS will seriously affect patients' quality of life as it can cause severe pain [3]. Furthermore, KS presence can result in severe complications, such as urinary obstruction, refractory urinary tract infections, and even irreversible kidney damage in severe cases [4, 5]. The formation of KS is a highly complex process. Growing evidence suggests KS should be considered a systemic disease rather than a localized urinary metabolic disorder. As demonstrated in preceding studies, there is a demonstrable correlation between the occurrence of KS and metabolic conditions, including obesity, hypertension and diabetes [6]. Some researchers have identified a notable increase in the risk of the progression to terminal renal disease in patients with KS [7].

Frailty is a degenerative trait characterized by progressive impairments across physiological systems with advancing age, significantly compromising survival rates at any stage of life [8]. Even minor external stressors can trigger a cascade of negative clinical outcomes in frail older adults [9, 10]. This condition encompasses pathological and physiological alterations across multiple systems, including the neuromuscular, metabolic, and immune systems, and can trigger or exacerbate various health complications [10]. Previous studies have established links between frailty and metabolic conditions, such as chronic kidney disease (CKD), hypertension, diabetes, serum uric acid level and age [11–17]. Previous research has primarily focused on the link between frailty and KS prevalence in diabetic populations [18]. Moreover, Liu et al. identified a significant association between oxidative balance score and frailty among adults older than 20 years of age [19]. These findings suggest that frailty may be pivotal in the formation of KS in the whole adult population. However, the relationship between frailty and KS formation in the whole adult remains poorly understood. Therefore, a hypothesis that frailty is strongly linked to the likelihood of developing KS in adults was put forward. In order to test this hypothesis, the objective was to evaluate the relationship between frailty and the prevalence of KS in participants from the National Health and Nutrition Survey (NHANES).

Methods

Data source

NHANES is a nationwide cross-sectional program conducted biennially by the Centers for Disease Control and Prevention (CDC). It gathers data on a range of demographic, socioeconomic, nutritional and health-related factors from a nationally appropriate sample of the U.S. populace. Through structured interviews, physical examinations, and lab tests, NHANES assesses participant's health issues. All research protocols are systematically examined and authorized by the National Center for Health Statistics Research Ethics Review Board, and this study was exempt from additional ethical review. Data for this study were accessed via the official NHANES website.

Study population

This study utilized data from the NHANES database for seven cycles from 2007 to 2020. The NHANES study analyzed a group of 20-year-old or older participants with complete data on KS prevalence. This group was then restricted to individuals with complete information on the relevant covariates. Only those 20-year-old participants or older with complete NHANES data on KS and no missing covariate information were incorporated into this study (Fig. 1).

Assessment of kidney stone

History of KS was assessed with the question, "Have you ever had kidney stones?" Participants who responded positively to this question were categorized as having a medical history of diagnosed KS. The reliability of these self-reported measures has been confirmed by previous studies [20, 21].

Assessment of frailty index and frailty status

The Frailty Index (FI), a continuous variable that ranges from 0 to 1 according to the severity of the deficit, was utilized to assess frailty. The FI assessed using the frailty index established by Wael Sabbah and his colleagues [22], which incorporates 49 diagnostic criteria following Searle's standard procedures [23]. 49-item frailty index encompassing various systems, including cognition (confusion and memory problems), dependence (activities of daily living), depression (PHQ-9), comorbidities (e.g., arthritis, diabetes, renal failure), general health and hospital utilization, physical performance (grip strength, body mass index (BMI)), and laboratory markers (glycohemoglobin, hemoglobin, lymphocytes) (Supplementary Table 1). This index was selected because it has been validated in large population-based studies and is well-suited for use with NHANES data due to its comprehensive inclusion of health deficits [24]. The FI value is calculated by dividing the participant's number of acquired deficits by the total number of potential deficits [22]. Consequently, FI is a continuously variable scale ranging from 0 to 1, with higher values denoting increased frailty. Participants who answered at least 80% of the

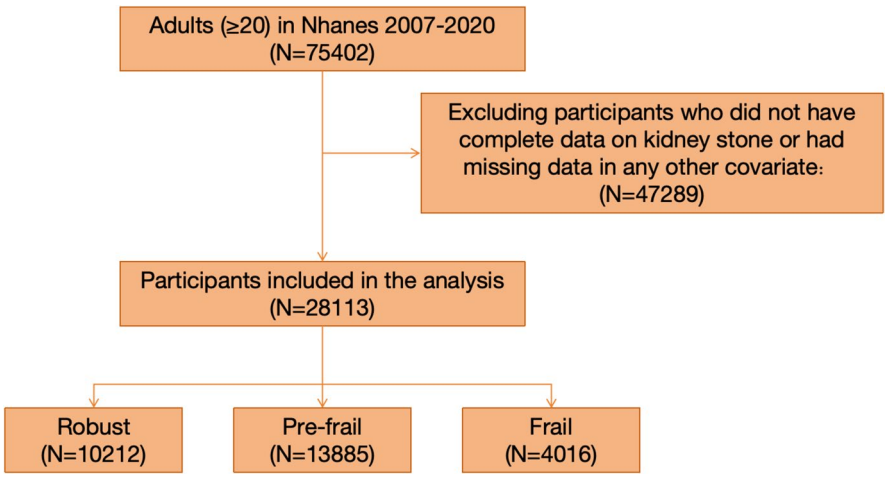

Fig. 1 The flowchart depicting sample selection for the National Health and Nutrition Examination Survey (NHANES) from 2007 to 2020

items were included to guarantee high-quality frailty diagnoses [24, 25]. As recommended in prior studies, frailty status was categorized into three distinct groups: "robust" (FI ≤ 0.10), "pre-frail" (0.10 < FI < 0.25), and "frail" (FI ≥ 0.25) [24, 26, 27].

Covariates definition

Building on preceding studies, a comprehensive set of covariates had been incorporated into this study, covering multiple dimensions, including questionnaire data, dietary habits, clinical examinations, laboratory assays, and demographics. These covariates included several categorical factors, including age, BMI (BMI = weight [kg]/height $[m]^2$), sex (2 categories: male and female), race (4 categories: Mexican American, Non-Hispanic Black, Non-Hispanic White and Other race), marital status recoded into 3 groups: having a partner (married, living with partner), no partner (widowed, separated, divorced), unmarried (never married). Poverty–income ratio (PIR), education level (3 categories: high school or equivalent, less than high school and more than high school), total energy intake (kcal), total water intake (total plain water drank yesterday—including plain tap water, water from a drinking fountain, water from a water cooler, bottled water, and spring water), sodium intake, calcium intake, recreational activity status, sedentary time, serum creatinine (Scr), Serum calcium, total cholesterol, serum uric acid, blood urea nitrogen (BUN), triglycerides, high-density lipoprotein (HDL), and smoking and drinking behaviors. Smoking status was categorized as follows: "Never" (smoked ≤ 100 cigarettes in a lifetime and not currently smoking); "Former" (smoked 100 + cigarettes in a lifetime and not currently smoking); or "Current" (smoked 100 + cigarettes in a lifetime and currently smoking). Drinking status: "Never" (had ≤ 12 drinks), "Former" (had ≥ 12 drinks in 1 year, did not drink last year, or did not drink last year but had ≥ 12 lifetime drinks), "Mild" (1–2 drinks per day for females, 2–4 for males), "Moderate" (2 + drinks per day for women, 3 + for men, or binge drinking 2 + days per month but < 5 days per month) and "Heavy" (3 + for women and 4 + for men, or binge drinking ≥ 5 days per month). Additionally, the presence of hypertension was defined by doctor-diagnosed hypertension, current medication uses for hypertension, or an abnormal blood pressure measurement result (systolic pressure ≥ 140 mmHg or diastolic pressure ≥ 90 mmHg). The presence of diabetes was defined by doctor-diagnosed diabetes, use of diabetes drugs (hypoglycemic drugs or insulin) or the lab results were abnormal (glycosylated haemoglobin ≥ 6.5%, fasting glucose ≥ 7.0 mmol/L, random blood glucose ≥ 11.1 mmol/L, two-hour oral glucose tolerance test ≥ 11.1 mmol/L).

Statistical analyses

Following the guidelines provided by the CDC, this study conducted refined statistical analyses. Continuous variables are reported as median (Q1–Q3), while categorical variables are presented as weighted percentages and counts. The statistical method assessed the differences in baseline characteristics (Chi-square tests and ANOVA). Model 1 consisted of a univariable logistic regression; Model 2 included adjustments for age, sex, race, education level, PIR, and marital status; Model 3 further adjusted for smoking status, alcohol consumption, BMI, diabetes status, and hypertension status, in addition to the variables in Model 2; Model 4 incorporated additional adjustments for total energy intake, total water intake, Scr, serum calcium, total cholesterol, triglycerides, HDL, serum uric acid, sodium intake, calcium intake, recreational activity status and sedentary time, alongside the

covariates in Model 3. The restricted cubic spline (RCS) model was used to evaluate the relationship of the potential nonlinear (median serving as the reference value; 10th, 50th, and 90th percentiles of the FI as knots). Hosmer–Lemeshow test was used to evaluate the goodness of fit of logistic regression model. Subgroup analyses and interaction testing were also performed to explore factors that may modify the association between frailty and KS prevalence. These subgroup analyses were not additionally adjusted for covariates, allowing for a direct assessment of the bivariate relationship within each subgroup. The discriminatory capacity of FI in predicting KS was assessed by examining receiver-operating characteristic (ROC) curves and calculating the area under the curve (AUC). Missing sedentary time data for 116 people and serum calcium data for 24 people were both interpolated using the median, while the remaining data were not missing. R software (version 4.3.3) was used for statistical analyses. Two-side p value < 0.05 was considered statistically significant.

Results

Baseline characteristics of participants

Table 1 shows the participant's characteristics in the 2007–2020 NHANES cohort. This study involved 28,113 individuals, with an overall KS prevalence of 9.576%. The sample included 49.332% males and 69.283% non-Hispanic White participants. The comparison of individuals with and without KS revealed significant differences across all baseline variables except for education, total energy intake, total water intake, total cholesterol, sodium intake, sedentary time and PIR ($p > 0.05$). Patients with KS not only had higher percentages in older males, non-Hispanic white participants, having a partner, former smokers, and mild drinkers ($p < 0.0001$) but also exhibited higher levels of Scr, serum uric acid, serum calcium, BUN, and triglycerides ($p < 0.0001$). Moreover, they also had a higher prevalence of metabolic conditions, such as higher BMI, hypertension rate and diabetes rate ($p < 0.0001$). Patients with KS have a lower calcium intake level and HDL level ($p < 0.0001$) and higher percentages in no recreational activity ($p = 0.008$). It is noteworthy that the FI in the KS group was significantly higher compared to the nonstone group [0.142(0.094–0.216) vs 0.112(0.073–0.172), $p < 0.0001$]. Furthermore, the rates of frail status (17.691% vs 9.791%, $p < 0.0001$) and pre-frail status (54.267% vs 46.929%, $p < 0.0001$) were demonstrably higher in the KS group than in the nonstone group.

Associations between the frailty and kidney stones

To examine the relationship between frailty and KS prevalence using the continuous variable (FI) and categorical factor (frailty status). The continuous FI analysis revealed a positive association with increased KS prevalence across all models (Table 2). Further stratification by frailty status showed that individuals classified as frail had a 1.731-fold higher likelihood of developing KS in the fully adjusted model (95% CI 1.406–2.131, p for trend < 0.0001) as compared to those in the robust group, which further shown the association between frailty and KS. In addition, the relationship between the FI and KS prevalence was further explored using a restricted cubic spline (RCS) model (Fig. 2). A nonlinear, positive correlation was observed, with the likelihood of KS increasing as the FI rose (P for nonlinearity = 0.0002). The Hosmer–Lemeshow test result ($p = 0.1362$) demonstrated a good calibration of the model with no significant difference between the predicted and observed probabilities (Supplementary Fig. 1). FI had a moderate ability to discriminate between individuals with and without KS (AUC value = 0.613) (Supplementary Fig. 2).

Subgroup analysis

Subgroup analyses were conducted based on sex, race, marital status, BMI, age, education, diabetes, hypertension, smoking status, and drinking status. Continuous variables were converted to categorical variables; the age is stratified into two tiers: "< 60" and "≥ 60". BMI was categorized into 3 distinct groups: "normal weight" (BMI ≤ 25), "overweight" (25 < BMI < 30) and "obesity"(BMI ≥ 30). A consistent relationship between frailty status/frailty index and KS prevalence was observed in all subgroups. It is worth noting that there were significant interactions between age, BMI, and hypertension with both the FI and frailty status, which means that the impact of these factors on KS likelihood may differ across subgroups. Specifically, increased frailty degree and KS likelihood were more pronounced in participants under 60 years of age, as well as in those non-hypertension individuals and normal-weight individuals (Fig. 3).

Discussion

This study showed that KS disease is associated with frailty in a countrywide population-representative sample of American adults. This research revealed a substantial correlation between an augmented FI and an elevated likelihood of KS. Higher frailty status levels were associated with the rise in KS prevalence, with both frail and pre-frail individuals showing a notably increased likelihood. This association's robustness was evident even after adjustment for potential confounding variables. Furthermore, there was a nonlinear positive correlation between the FI and the occurrence of KS was observed. The correlation between frailty and kidney stone remained consistent across subgroups stratified by sex, race, marital

Table 1 Basic characteristics of the study population in NHANES 2007–2020 ($n = 28,113$)

Variable	Total	No kidney stones	With kidney stones	*p* value
N (participants)	28,113	25,421	2692	
Age (year), Median (Q1–Q3)	47.000(33.000–60.000)	46.000(32.000–59.000)	54.000(41.000–64.000)	< 0.0001
Sex n (%)				< 0.0001
Female	14,091(50.668)	12,923(51.375)	1168(44.255)	
Male	14,022(49.332)	12,498(48.625)	1524(55.745)	
Race, n (%)				< 0.0001
Mexican American	4018 (8.005)	3683(8.223)	335(6.032)	
Non-Hispanic Black	5853(10.048)	5498(10.543)	355 (5.560)	
Non-Hispanic White	12,153(69.283)	10,662(68.314)	1491(78.082)	
Other race	6089(12.663)	5578(12.921)	511(10.327)	
Marital, n (%)				< 0.0001
Having a partner	16,818(64.130)	15,082(63.465)	1736(70.154)	
No partner	6077(17.699)	5392(17.445)	685(20.002)	
Unmarried	5218(18.172)	4947(19.090)	271(9.844)	
Education, n (%)				0.565
High school or equivalent	6430(23.116)	5836(23.151)	594(22.797)	
Less than high school	5926(13.394)	5327(13.308)	599(14.171)	
More than high school	15,757(63.490)	14,258(63.541)	1499(63.032)	
Total energy intake (kcal), Median (Q1–Q3)	2034.000(1521.000–2694.000)	2036.000(1522.000–2705.000)	2020.000(1496.000–2628.000)	0.265
Total water intake (g), Median (Q1–Q3)	900.000(296.250–1740.000)	900.000(300.000–1740.000)	870.000(240.000–1740.000)	0.251
Scr (mg/dl), Median (Q1–Q3)	0.850(0.720–0.990)	0.840(0.720–0.990)	0.890(0.750–1.030)	< 0.0001
Serum uric acid (mg/dl), Median (Q1–Q3)	5.300(4.400–6.300)	5.300(4.400–6.300)	5.600(4.600–6.500)	< 0.0001
Serum calcium (mg/dl), Median (Q1–Q3)	9.400(9.200–9.600)	9.400(9.200–9.600)	9.300(9.100–9.600)	0.014
BUN (mg/dl), Median (Q1–Q3)	13.000(10.000–16.000)	13.000(10.000–16.000)	14.000(11.000–17.000)	< 0.0001
Triglycerides (mg/dl), Median (Q1–Q3)	119.000(80.000–183.000)	118.000(79.000–181.000)	135.000(90.000–200.000)	< 0.0001
Total cholesterol (mg/dl), Median (Q1–Q3)	190.000(165.000–218.000)	190.000(165.000–219.000)	189.000(165.000–216.000)	0.303
HDL (mg/dl), Median (Q1–Q3)	51.000(42.000–62.000)	51.000(42.000–63.000)	47.000(40.000–57.000)	< 0.0001
PIR, Median (Q1–Q3)	3.160(1.570–5.000)	3.150(1.570–5.000)	3.180(1.650–5.000)	0.887
BMI, Median (Q1–Q3)	28.100(24.300–32.700)	27.900(24.180–32.500)	29.640(25.780–34.200)	< 0.0001
Calcium intake (mg), Median (Q1–Q3)	867.000(580.000–1254.000)	869.000(582.000–1258.000)	833.000(550.000–1221.000)	0.041
Sodium intake (mg), Median (Q1–Q3)	3279.000(2365.000–4453.000)	3280.000(2369.000–4458.000)	3270.000(2327.000–4406.000)	0.579
Sedentary time (min), Median (Q1–Q3)	360.000(240.000–480.000)	360.000(240.000–480.000)	360.000(240.000–480.000)	0.19
Diabetes, n (%)				< 0.0001
No	24,233(89.667)	22,158(90.601)	2075(81.193)	
Yes	3880(10.333)	3263(9.399)	617(18.807)	
Hypertension, n (%)				< 0.0001
No	16,219(62.659)	15,039(64.352)	1180(47.298)	
Yes	11,894(37.341)	10,382(35.648)	1512(52.702)	
Smoke status, n (%)				< 0.0001
Never	15,646(55.992)	14,322(56.601)	1324(50.460)	
Former	6787(25.008)	5964(24.443)	823(30.139)	
Now	5680(19.000)	5135(18.956)	545(19.402)	
Alcohol status, n (%)				< 0.0001
Never	3599(9.714)	3269(9.766)	330(9.241)	
Former	3606(10.935)	3123(10.427)	483(15.539)	
Mild	10,203(38.587)	9155(38.232)	1048(41.804)	
Moderate	4753(18.698)	4360(18.852)	393(17.306)	
Heavy	5952(22.066)	5514(22.723)	438(16.110)	
Recreational activity				< 0.0001

Table 1 (continued)

Variable	Total	No kidney stones	With kidney stones	*p* value
No	14,117(43.853)	12,591(43.174)	1526(50.018)	
Moderate	7314(28.347)	6608(28.219)	706(29.508)	
Vigorous	2165(8.351)	2013(8.647)	152(5.666)	
Both	4517(19.449)	4209(19.960)	308(14.807)	
Frailty index, Median (Q1–Q3)	0.114(0.073–0.176)	0.112(0.073–0.172)	0.142(0.094–0.216)	< 0.0001
Frailty status, n (%)				< 0.0001
Robust	10,212(41.767)	9602(43.280)	610(28.042)	
Pre-frail	13,885(47.657)	12,444(46.929)	1441(54.267)	
Frail	4016(10.575)	3375(9.791)	641(17.691)	

Table 2 Univariate and multivariate logistic regression analyses of the relationship between frailty index/frailty status and kidney stones

Variable	Model1		Model2		Model3		Model4	
	OR (95%CI)	*p* value	OR (95%CI)	*p* value	OR (95%CI)	*p* value	OR (95%CI)	*p* value
Frailty index	1.038(1.033–1.042)	< 0.0001	1.034(1.028–1.039)	< 0.0001	1.021(1.015–1.028)	< 0.0001	1.021(1.015–1.028)	< 0.0001
Frailty status								
Robust	ref		ref		ref		ref	
Pre-frail	1.785(1.58-,2.014)	< 0.0001	1.691(1.495–1.914)	< 0.0001	1.468(1.289–1.672)	< 0.0001	1.458(1.280–1.662)	< 0.0001
Frail	2.789(2.390–3.255)	< 0.0001	2.455(2.064–2.921)	< 0.0001	1.766(1.440–2.167)	< 0.0001	1.734(1.415–2.124)	< 0.0001
p for trend	< 0.0001		< 0.0001		< 0.0001		< 0.0001	

To yield integer values without changing the distribution, the frailty index was multiplied by 100

OR, odds ratio; 95% CI, 95% confidence interval

Model 1 did not incorporate any variable adjustments

Model 2 adjusted for age + sex + race + education level + PIR + marital status

Model 3 adjusted for Model 2 + smoke status + alcohol status + BMI + diabetes + hypertension

Model 4 adjusted for Model 3 + total energy intake + total water intake + Scr + total cholesterol + triglycerides + HDL + serum uric acid + recreational activity + calcium intake + sodium intake + sedentary time + Serum calcium

status, education, diabetes, smoke statues, and alcohol status. Notably, age, hypertension and BMI significantly influenced this relationship.

This study initially explores the association between frailty and KS. Frailty has been demonstrated to be a major contributor to adverse health outcomes in various clinical contexts [28]. Previous research has established links between frailty and conditions such as systemic atherosclerosis, diabetes, etc. [29–31]. In addition, frailty has been demonstrated to be associated with an elevated risk of mortality from a variety of causes [32, 33]. A previous study about diabetic patients pointed out that the FI was found to raise the risk for developing KS in people with diabetes [18]. Moreover, previous studies about diabetic patients pointed out that the FI was found to raise the risk for developing urinary tract infection and end-stage renal disease in people with diabetes which were the risk factors of KS [34, 35]. Given that numerous studies have demonstrated the close relationship between frailty and kidney-related outcomes, such as CKD and serum uric acid level [11, 16, 17], this may provide support for the biological plausibility of the association between frailty and kidney stones. Therefore, this study further advocated that frailty plays a significant role in the formation of KS in the general adult population. Even if various potential influencing factors were accounted for, there was a strong correlation between a higher FI and a higher likelihood of KS formation was observed. That is to say, frailty may emerge as a significant risk factor for KS formation, but this requires further confirmation through longitudinal studies in the future.

This stratified analysis showed that frailty had a greater relative impact on KS venture in those individuals who are normal weight, younger than 60 years old or without hypertension. Specifically, frailty had the greatest relative effect on the likelihood of KS in normal-weight individuals, whereas the impact was less pronounced in overweight and obese individuals.

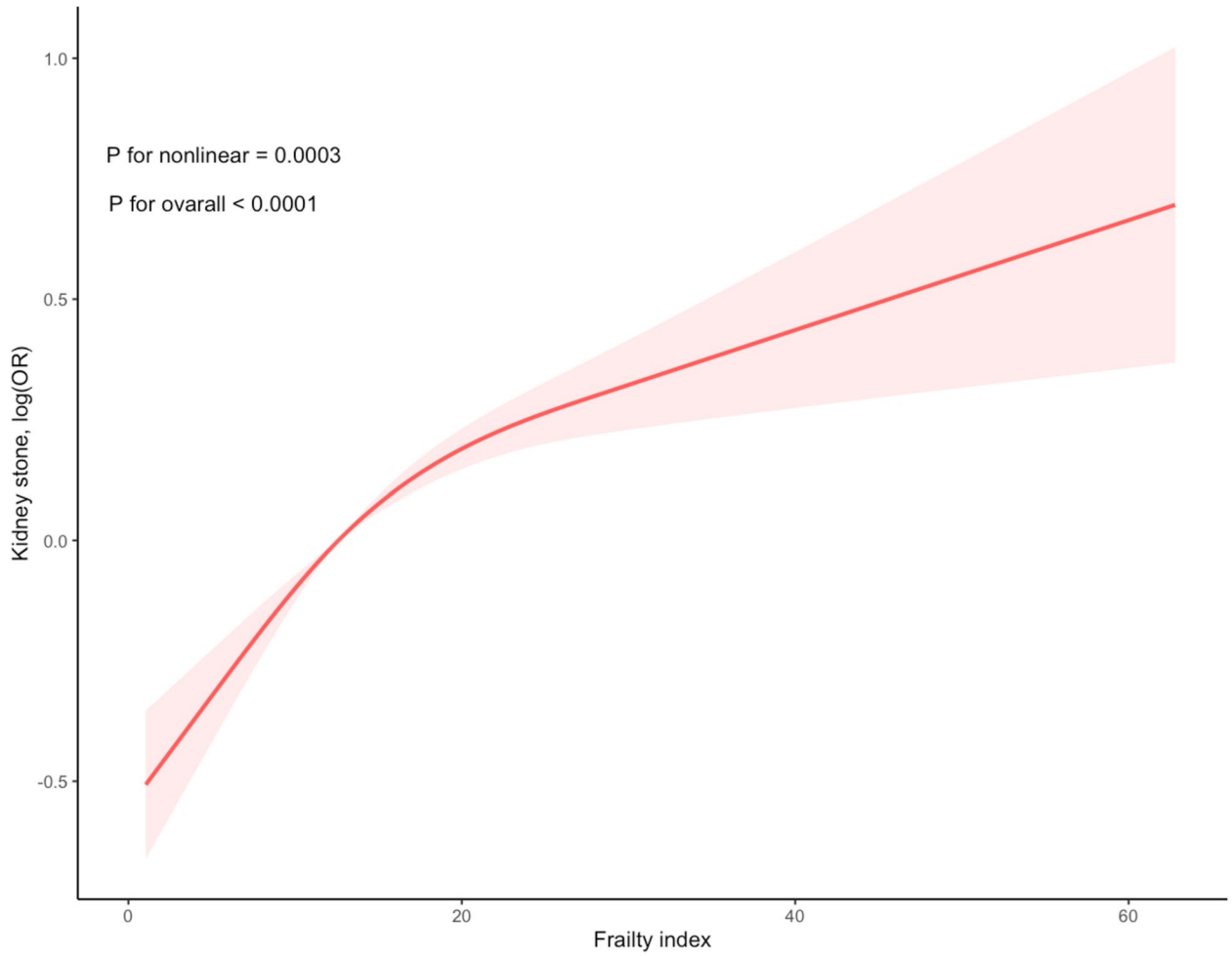

Fig. 2 Restricted cubic spline of the association between frailty index and kidney stone adjusted for all covariates. To yield integer values without changing the distribution, the frailty index was multiplied by 100

Individuals with obesity and overweight exhibit a higher overall likelihood of KS, predominantly driven by high serum calcium concentrations in visceral adipose depots rather than the additional contribution of frailty [36]. It can be speculated that this may be the reason that the effect of frailty on KS was more pronounced in people of normal weight. Moreover, the results show that frailty had the greatest relative effect on KS in individuals younger than 60. Younger individuals generally have a lower baseline likelihood for KS than older individuals. Therefore, the additional risk introduced by frailty may appear relatively larger in younger populations. Frailty in younger individuals may indicate severe underlying health issues or premature biological age, which could amplify the relative effect on KS formation. Thus, frailty had a greater relative effect in younger individuals. As for the hypertension subgroup, frailty appeared to have a more significant relative effect on the likelihood of KS in individuals without hypertension. The observed effects may be attributed to the use of antihypertensive medications in patients with hypertension. Many antihypertensive drugs also exhibit stone-preventive properties [37–40]. For example, thiazide diuretics, widely prescribed for hypertension, exert their effects by inhibiting the Na + -Cl − symporter in the distal convoluted tubule, which reduces sodium and water reabsorption, thereby promoting diuresis [37, 38]. Moreover, nifedipine works by inhibiting Ca2 + influx and prostaglandin synthesis, leading to ureteral smooth muscle relaxation, reduced spasms, and enhanced peristalsis, thereby facilitating stone expulsion [40]. Those may explain why frailty exerts a greater relative effect on the likelihood KS in people without hypertension. In addition to this, the impact of frailty on KS formation may be attenuated by the influence of other confounding factors, as older adults, obese individuals, and hypertensive patients generally carry more risks than their counterparts.

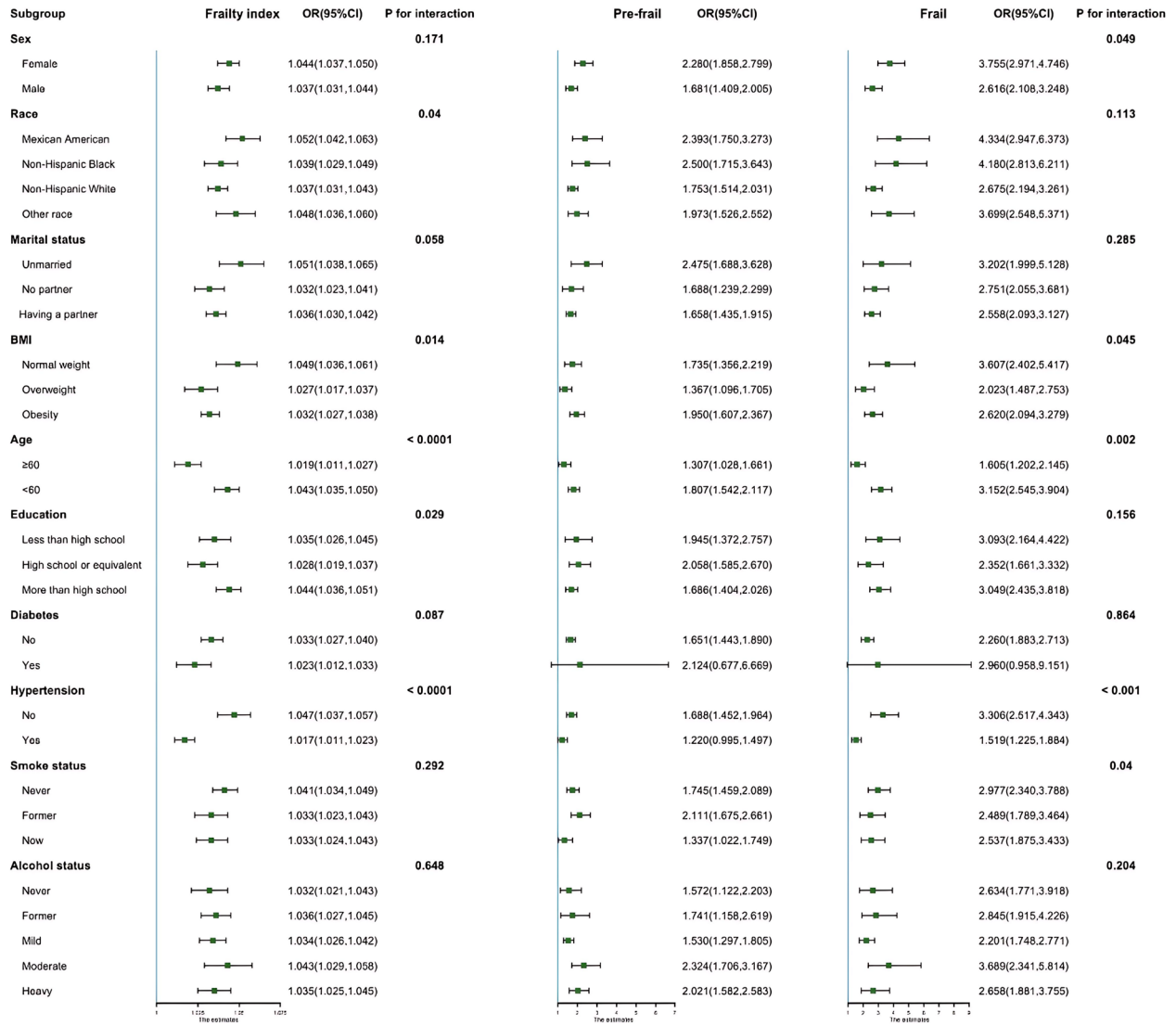

Fig. 3 Subgroup analysis of the association between frailty index, frail status and prevalence of kidney stones disease. To yield integer values without changing the distribution, the frailty index was multiplied by 100

This study includes a large and diverse cohort of participants from the NHANES 2007–2020 dataset, significantly increasing the statistical power and generalizability of the results. This extensive dataset provides valuable and comprehensive insights into the relationship under investigation. In addition, the FI and frailty status were used in this study to analyze the association between frailty and KS, respectively, and a consistent result was obtained. Moreover, to the authors' knowledge, this is the first study to evaluate the relationship between KS and frailty in the adult population through the FI and frailty status. Because of these advantages, the results of this study have high reliability and correlation.

There are also several limitations in this study. Firstly, it is hard to draw an exact causality between frailty and KS because of the peculiarity of cross-sectional studies. In order to establish a more certain causal relationship, longitudinal studies or interventional trials are required in the future. Secondly, information regarding kidney stones and comorbidities was self-reported, which may be subject to recall bias and other possible biases such as poor memory. Moreover, while efforts were made to adjust for known confounders, residual and unmeasured confounding factors may still affect the results. Finally, it is necessary to acknowledge that the findings from this study are exclusively applicable to Americans and cannot

be extrapolated to other groups. Further research on different groups is needed in the future.

Conclusion

This study exhibited a positive relationship between frailty and the odds of KS formation in adults, suggesting a potential contribution of frailty to an increase in the likelihood of KS formation. Nevertheless, the causal association between frailty and KS cannot be established due to the limits of the cross-sectional study nature. In the future, longitudinal studies or interventional trials are warranted to understand the underlying mechanisms and gain a more comprehensive insight into this association.

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s40001-025-02672-7.

Additional file 1.

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Author contributions
GYZ.Y., RF.L. and YD.L. wrote the main manuscript text and XQ.Z., T.H. and FY.L. prepared All Tables and Figures. All authors reviewed the manuscript.

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Data availability
The dataset analyzed during this study can be found in NHANES: https://www.cdc.gov/nchs/nhanes/

Declarations

Ethics approval and consent to participate
The NCHS Ethics Review Committee has approved NHANES. The patient/participant provided written informed consent to participate in this study.

Consent to publications
Not applicable.

Competing interests
The authors declare no competing interests.

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