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Associations between the conicity index and kidney stone disease prevalence and mortality in American adults

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Kidney Stone Disease (KSD) is a prevalent urological condition, while abdominal obesity is on the rise globally. The conicity index, measuring body fat distribution, is crucial but under-researched in its relation to KSD and all-cause mortality. This study, using data from 59,842 participants in the NHANES (2007–2018), calculated the conicity index from waist circumference, height, and weight. Logistic regression and Cox models revealed a significant positive correlation: each 0.1 unit increase in the conicity index was linked to a 23% rise in KSD odds (OR: 1.23, 95% CI: 1.14, 1.35) and higher predictive ability compared to traditional measures (AUC = 0.619). In KSD patients, this increase corresponded to a 44% higher risk of all-cause mortality (HR: 1.44, 95% CI: 1.14, 1.82), and in non-KSD patients, a 53% increase (HR: 1.53, 95% CI: 1.37, 1.70). Serum albumin and Red Cell Distribution Width (RDW) partially mediated these relationships. Addressing central obesity could significantly lower the risks of KSD and mortality.

Keywords Kidney stone disease, Conicity index, All-cause mortality, Serum albumin, Red cell distribution width, NHANES

Abbreviations

KSD	Kidney stone disease
NHANES	National health and nutrition examination survey
RDW	Red cell distribution width
NCHS	National center for health statistics
BMI	Body mass index
WC	Waist circumference
WHR	Waist-hip ratio
WHtR	Waist-height ratio
BRI	Body roundness index
NDI	National death index
PIR	Poverty income ratio
CVDs	Cardiovascular and cerebrovascular diseases
TC	Total cholesterol
ORs	Odds ratios
HRs	Hazard ratios
CIs	Confidence intervals

Obesity, characterized by its multifaceted nature and escalating prevalence, now affects nearly one-third of the global population[1,2], with abdominal obesity being particularly concerning due to its links with chronic diseases such as hypertension, type 2 diabetes, and cardiovascular disorders[3–5]. Commonly used indicators of abdominal obesity include Body Mass Index (BMI), Waist Circumference (WC), Waist-Hip Ratio (WHR), Waist-Height Ratio (WHtR), and Body Roundness Index (BRI), which are extensively applied in clinical and epidemiological studies to assess obesity and its associated health risks. In recent years, the conicity index has emerged as a novel tool for evaluating abdominal obesity. This index, based on the premise that individuals with significant

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abdominal tissue resemble a double-conic shape as opposed to a cylindrical shape, serves as a robust indicator of body fat distribution[6] and has been particularly associated with cardiovascular diseases and metabolic syndrome. Compared to traditional metrics, the conicity index may provide a more precise assessment of abdominal obesity, thereby enhancing the prediction of obesity-related health risks. Typically, a higher conicity index indicates more severe abdominal obesity and, consequently, greater associated health risks.

Kidney Stone Disease (KSD) is a prevalent urological condition with an increasing global incidence, affecting about 11.0% of adults in the U.S.[7,8], particularly middle-aged males between 40 and 60 years old. The etiology of KSD is not fully understood but is thought to involve genetic, dietary, and uric acid level factors. Obesity, diabetes, and high-salt diets are recognized risk factors for KSD[9,10], which not only impacts health but also imposes significant economic and healthcare burdens[11]. Therefore, adopting healthy lifestyles is crucial in reducing the burden of this disease.

Previous studies have shown a close relationship between higher Body Mass Index (BMI) and the incidence of KSD[12]; however, BMI is insensitive to the deposition of abdominal fat and does not adequately account for differences in fat distribution and quality among individuals. The conicity index, which incorporates height, weight, and WC, offers a superior metric for assessing abdominal fat accumulation and distinguishing potential abdominal obesity[13,14]. Yet, studies exploring the association between the conicity index and both the occurrence of KSD and all-cause mortality in these patients are limited. Hence, this research aims to utilize the extensive dataset from the National Health and Nutrition Examination Survey (NHANES) spanning from 2007 to 2018 to calculate the conicity index and further investigate its relationship with the prevalence of KSD and all-cause mortality among patients.

Our study not only investigates the direct impacts of the conicity index but also examines potential mediators such as serum albumin levels and Red Cell Distribution Width (RDW). Serum albumin is a critical marker of nutritional status and overall health, with low levels consistently associated with increased morbidity and mortality across various populations[15,16]. Furthermore, RDW, considered a potential risk factor for the development of chronic diseases[17], has been identified as an independent predictor of mortality in several conditions, including cardiovascular diseases and cancers[18]. Understanding the roles of these mediators is crucial, as they may influence the relationship between the conicity index, KSD prevalence, and all-cause mortality. Therefore, this study evaluates the potential mediating effects of serum albumin and RDW on these outcomes.

Methods

Study design and population

The National Center for Health Statistics (NCHS) conducts an extensive program known as the National Health and Nutrition Examination Survey (NHANES), aimed at collecting health-related data biennially from a representative sample of U.S. citizens. The primary objective is to assess the health and nutritional status of Americans. This program has been approved by the National Health and Human Services Institutional Review Board to ensure informed consent from all participants. Data collected through NHANES, accessible at "www.cdc.gov/nchs/nhanes/", comprises five key sections: demographic, dietary, examination, laboratory, and questionnaire data.

We downloaded NHANES data spanning six cycles from 2007 to 2018, totaling 59,842 individuals. Individuals aged 20 and over with complete kidney stone history, based on self-reported responses to the query "Have you ever had kidney stones?" (Yes or No, N = 34,679), were initially considered. After excluding participants missing conicity index data (N = 3444), those missing follow-up data (N = 68), and necessary covariates (N = 6641), a total of 24,526 participants were included in our study (Fig. 1).

Calculation of conicity index and KSD history acquisition

The primary exposure variable in our study is the conicity index, calculated using the formula: Conicity index $= 0.109^{(-1)}$ WC(m)[Weight(kg)/Height(m)]$^{(-0.5)}$[19]. One of the outcomes assessed is the prevalence of KSD, determined by participants' responses to the questionnaire item "Have you ever had kidney stones?" with a "Yes" indicating a diagnosis of KSD and "No" indicating no KSD.

Mortality ascertainment

To explore whether the conicity index correlates with all-cause mortality risk among individuals with or without KSD, we conducted probabilistic matching between study-specific identifiers (SEQN) and the National Death Index (NDI) through December 31, 2019. We utilized the 'MORTSTAT' variable to denote mortality status and 'PERMTH_EXM' for follow-up time, calculated in months from baseline until death, loss to follow-up, or December 31, 2019.

Assessment of covariates

This study includes a comprehensive covariate analysis across several domains. Demographic factors encompass age ($<50, \geq 50$), sex (male, female), race (non-Hispanic white, non-Hispanic black, Hispanic and others), education level (< high school, high school, > high school), marital status (married, not married), and the Poverty Income Ratio (PIR; <1.0, 1.0–2.0, ≥ 2.0). Lifestyle factors consider physical activity levels (inactive, moderate, vigorous, both moderate and vigorous), smoking status (never smokers, former smokers, current smokers), and alcohol use (yes, no), determined through two 24-h dietary recalls, with participants reporting alcohol consumption at least once being defined as drinkers. Dietary factors include intake of calcium (mg), vitamin D (mcg), and water (gm)[20,21], averaged from two 24-h dietary recalls or taken as a single recall if only one is available. Health status indicators include BMI categories (<20, 20–25, 25–30, ≥ 30), self-reported hypertension (yes, no), diabetes (yes, no), and cardiovascular and cerebrovascular diseases (CVDs), with a positive history of congestive heart failure, coronary artery disease, angina, myocardial infarction, or stroke considered as 'yes';

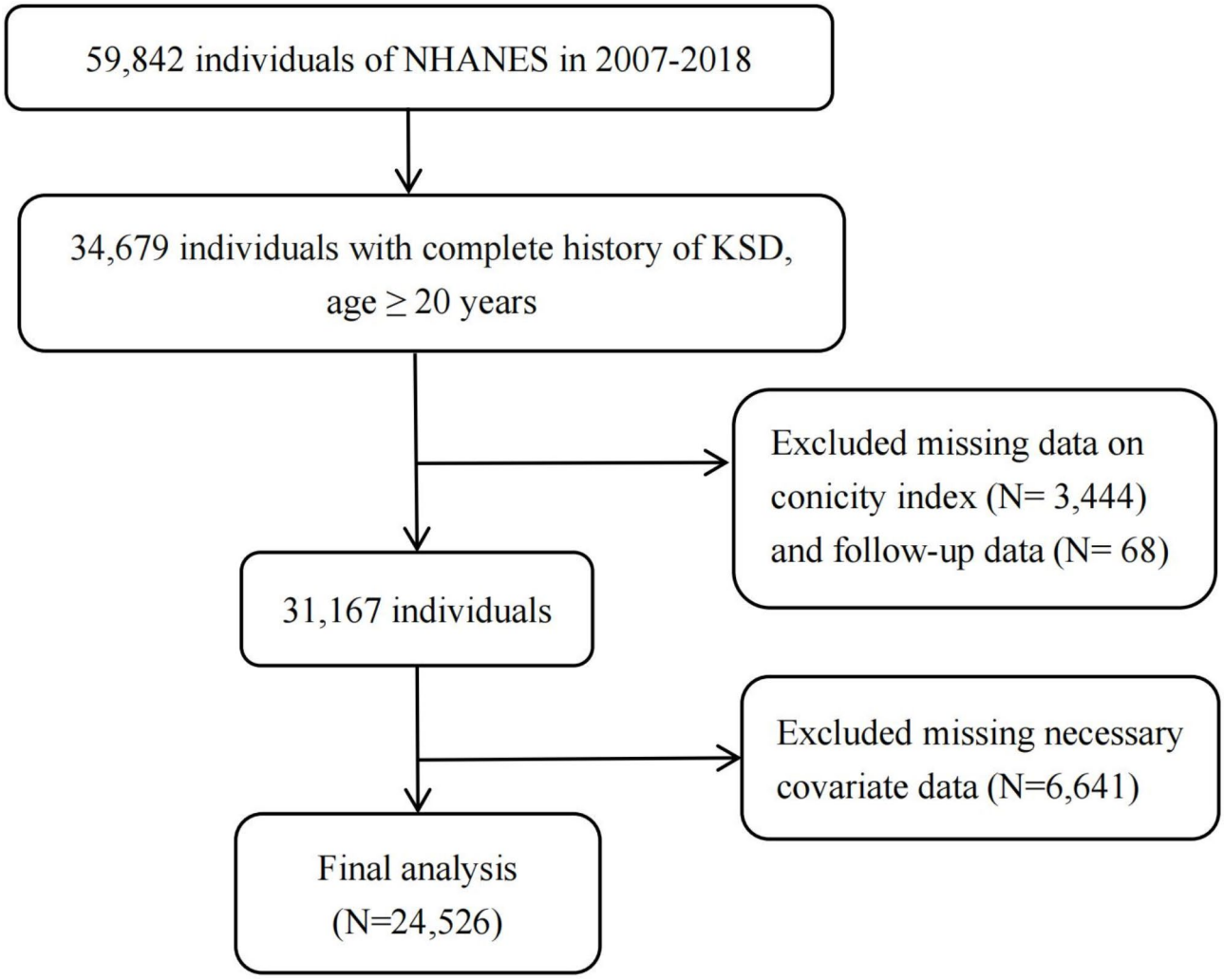

Fig. 1. Flow chart of the study.

otherwise, 'no'. Additionally, some laboratory indices, such as total cholesterol (TC, mmol/L), glycohemoglobin, uric acid (mg/dL), are also considered.

Statistical analysis

To ensure our analysis accurately estimates sampling errors and represents the U.S. population, we considered sample weights, including two-year examination weights (WTMEC2YR), stratification (SDMVSTRA), and primary sampling units (SDMVPSU), accommodating the complex survey design. The conicity index was divided into quartiles for analysis: Q1: < 1.24912, Q2: 1.24912–1.31351, Q3: 1.31351–1.37576, Q4: > 1.37576. Continuous variables are presented as survey-weighted means with corresponding 95% confidence intervals (CIs), and categorical variables are shown using survey-weighted percentages and 95% CIs. Survey-weighted linear regression is used to compare differences between continuous variables, while survey-weighted chi-square tests compare categorical variables. The association between the conicity index and KSD prevalence is analyzed using weighted multivariable logistic regression, represented by odds ratios (ORs) with 95% CIs. In the sensitivity analysis, we employed ROC curve analysis to evaluate the diagnostic value of the conicity index compared to traditional abdominal obesity indicators in predicting kidney stones. To explore the relationship between the conicity index and all-cause mortality, weighted multivariable COX proportional hazard models calculate hazard ratios (HRs) and 95%CIs. Survival differences among the quartiles of the conicity index are depicted using Kaplan–Meier curves and compared via log-rank tests. Potential nonlinear relationships between the conicity index and both KSD and all-cause mortality are further assessed through smooth curve fitting based on the Generalized additive model and Cox model with restricted cubic splines. To control for confounders, three regression models are constructed: Model 1: non-adjusted; Model 2: adjusted for sex, age, race, education, marital status, PIR, BMI, physical activity, smoke, and alcohol use.; Model 3: further adjusted for hypertension, diabetes, CVDs, glycohemoglobin, TC, uric acid, vitamin D intake, calcium intake and water intake. To assess the potential bias due to missing covariate data, 50 multiple imputations are performed using the missForest R package[22]. Mediation effects are analyzed using the 'mediation' package, examining if the relationships between

variables are partially explained by mediators. In this study, we specifically explore whether serum albumin and RDW mediate the relationship between the conicity index (X) and both KSD (Y) and all-cause mortality (Y). The total effect represents the comprehensive impact of X on Y, unaffected by any mediators; the indirect effect indicates the influence of X on Y through the mediator (M); the direct effect denotes the direct influence of X on Y, controlling for M. If the indirect effect is significant, a mediation effect is present. Additionally, subgroup analyses are conducted to explore differences among various populations, and interaction test p-values are calculated. A two-sided P-value of < 0.05 was considered statistically significant. All statistical analyses were performed using R version 4.2.3 and the EmpowerStats software.

Ethics approval and consent to participate

The data for this study were sourced from publicly accessible databases. All included studies received approval from their respective ethics committees, and participants gave informed consent. Since original data were not utilized, this study did not require specific ethical approval. Researchers can freely access and download the relevant data for research and publication purposes.

Results

Baseline characteristics

A total of 24,526 participants were included in this analysis, with 9.73% (2,386) diagnosed with KSD. After applying survey weights, 51.95% of the study population were females and 68.91% were non-Hispanic whites. The weighted mean age was 47.38 years, and the mean conicity index was 1.308. Weighted baseline characteristics for participants with and without KSD are presented in Table 1. Specifically, those with KSD were more likely to be male, aged ≥ 50 years, non-Hispanic white, married, obese (BMI ≥ 30), current or former smokers, non-drinkers, and more likely to have hypertension, diabetes, and CVDs. Additionally, they exhibited higher levels of conicity index, glycohemoglobin, and uric acid, along with lower TC levels and reduced calcium intake (all $p < 0.05$).

Associations between the conicity index and KSD

Significant positive associations were found between the conicity index and the prevalence of KSD. After adjusting for covariates in Model 3, the prevalence rates of KSD by increasing quartiles of conicity index (Q1-Q4) were represented by weighted ORs and 95% CIs as follows: 1.00 (Reference), 1.16 (0.95, 1.41), 1.52 (1.27, 1.82), and 1.62 (1.32, 1.99), with a P for trend < 0.001 (Table 2). When analyzed as a continuous variable (Model 3), the conicity index was positively correlated with KSD, with each 0.1-unit increase associated with a 23% increase in the odds of having KSD (OR: 1.23, 95% CI: 1.14, 1.35). A smoothing spline curve confirmed the linear relationship between the conicity index and KSD (Fig. 2). The robustness of these findings was supported by multiple imputation analysis (N = 31,167) (Table S1). Subgroup analyses adjusted by Model 3 based on sex, age, BMI, smoke, alcohol use, hypertension, and diabetes (Fig. 3) revealed stronger associations in males, those younger than 50, and those without diagnosed hypertension or diabetes (all P-interaction < 0.05).

In our sensitivity analysis, we compared the predictive performance of the conicity index with other traditional indicators of abdominal obesity—including WC, WHR, BRI, WHtR, and BMI—for the prevalence of KSD. This comparison was conducted by plotting ROC curves (Fig. 4). The results revealed that the conicity index had the strongest diagnostic predictive ability, with an Area Under the Curve (AUC) of 0.619. This performance was superior to that of WC (AUC = 0.601), WHR (AUC = 0.598), BRI (AUC = 0.594), WHtR (AUC = 0.594), and BMI (AUC = 0.567), demonstrating higher diagnostic efficiency.

Associations between the conicity index and all-cause mortality

By December 31, 2019, the median follow-up time was 6.67 years (interquartile range: 3.83–9.83 years), during which 8.64% (2,118 individuals) died. A significant positive correlation was observed between the conicity index and all-cause mortality. Weighted Cox regression analysis (Model 3) demonstrated that higher quartiles of the conicity index (Q1-Q4) were associated with increasing adjusted HRs and 95% CIs for all-cause mortality: 1.00 (Reference), 1.42 (1.08, 1.88), 1.99 (1.48, 2.69), and 2.51 (1.84, 3.43), with a P for trend < 0.001 (Table 3). As a continuous variable, each 0.1 increase in the conicity index corresponded to a 51% increase in the adjusted risk of all-cause mortality for all participants (HR: 1.51, 95% CI: 1.36, 1.67), 44% for those with KSD (HR: 1.44, 95% CI: 1.14, 1.82), and 53% for those without KSD (HR: 1.53, 95% CI: 1.37, 1.70). Importantly, the interaction of KSD status on the association between the conicity index and all-cause mortality was not significant (P = 0.616). Smoothing curves further validated the positive linear relationships (Fig. 5A–C). Multiple imputation analysis confirmed the robustness of these findings (Table S2). Kaplan–Meier survival curves illustrated that higher conicity indices were associated with increased all-cause mortality rates, regardless of KSD status (all log-rank p-values < 0.001, as shown in Fig. 6A–C). Subgroup analysis findings were consistent across all participants (Table S3), particularly noting stronger positive correlations in individuals previously undiagnosed with hypertension or diabetes (both P-interaction < 0.05).

Mediation analysis

In our study, we evaluated the mediation effects of serum albumin and RDW on the impact of the conicity index on KSD and all-cause mortality. The analysis indicated that the conicity index's indirect effects through albumin on KSD and all-cause mortality were 0.002 (95% CI: 0.001, 0.003), accounting for 9.8% of the total effect, and 0.056 (95% CI: 0.043, 0.070), accounting for 14.6% of the total effect, respectively (Fig. 7A,C). After controlling for albumin, the direct effects on KSD and all-cause mortality were 0.016 (95% CI: 0.010, 0.023) and 0.328 (95% CI: 0.266, 0.394), respectively. The conicity index's indirect effects through RDW on KSD and all-cause mortality were 0.001 (95% CI: 0.001, 0.002), accounting for 7.6% of the total effect, and 0.031 (95% CI: 0.017, 0.045),

Characteristics	Overall (N = 24526)	No KSD history (N = 22140)	KSD history (N = 2386)	P-value
Sex (%)				< 0.001
Male	48.05 (47.38, 48.72)	47.21 (46.42, 48.01)	55.52 (52.74, 58.26)	
Female	51.95 (51.28, 52.62)	52.79 (51.99, 53.58)	44.48 (41.74, 47.26)	
Age (year)	47.38 (46.89, 47.87)	46.74 (46.23, 47.25)	53.13 (52.42, 53.85)	< 0.001
Age group (%)				< 0.001
< 50	54.95 (53.56, 56.33)	56.58 (55.13, 58.02)	40.40 (37.95, 42.90)	
≥ 50	45.05 (43.67, 46.44)	43.42 (41.98, 44.87)	59.60 (57.10, 62.05)	
Race (%)				< 0.001
Non-Hispanic white	68.91 (66.13, 71.56)	67.82 (65.00, 70.52)	78.60 (75.60, 81.32)	
Non-Hispanic black	10.15 (8.85, 11.62)	10.68 (9.32, 12.20)	5.44 (4.45, 6.63)	
Hispanic and others	20.94 (18.97, 23.06)	21.50 (19.51, 23.64)	15.97 (13.76, 18.46)	
Education (%)				0.833
< High school	14.60 (13.47, 15.80)	14.54 (13.41, 15.75)	15.12 (13.37, 17.05)	
High school	22.91 (21.77, 24.08)	22.92 (21.76, 24.12)	22.82 (20.38, 25.47)	
> High school	62.49 (60.58, 64.37)	62.54 (60.60, 64.44)	62.06 (58.82, 65.20)	
Marital status (%)				< 0.001
Not married	43.51 (42.03, 45.01)	44.29 (42.75, 45.84)	36.57 (33.78, 39.46)	
Married	56.49 (54.99, 57.97)	55.71 (54.16, 57.25)	63.43 (60.54, 66.22)	
PIR (%)				0.086
< 1.0	13.89 (12.79, 15.06)	14.06 (12.92, 15.29)	12.33 (10.92, 13.90)	
1.0–2.0	20.23 (19.18, 21.32)	20.12 (19.05, 21.24)	21.20 (19.19, 23.36)	
≥ 2.0	65.89 (64.03, 67.70)	65.82 (63.92, 67.67)	66.47 (63.61, 69.21)	
BMI (kg/m^2)	29.13 (28.96, 29.30)	28.96 (28.79, 29.13)	30.65 (30.32, 30.99)	< 0.001
BMI (%)				< 0.001
< 20	4.47 (4.10, 4.88)	4.70 (4.29, 5.14)	2.49 (1.81, 3.43)	
20–25	24.51 (23.55, 25.50)	25.32 (24.31, 26.36)	17.27 (15.29, 19.44)	
25–30	32.91 (31.97, 33.87)	32.95 (31.95, 33.96)	32.59 (30.07, 35.23)	
≥ 30	38.10 (36.95, 39.27)	37.04 (35.85, 38.24)	47.64 (45.11, 50.18)	
Physical activity (%)				0.012
Inactive	53.19 (51.93, 54.44)	53.31 (52.00, 54.63)	52.08 (49.22, 54.93)	
Moderate	24.73 (23.85, 25.64)	24.96 (24.00, 25.93)	22.75 (20.82, 24.81)	
Vigorous	3.93 (3.60, 4.30)	3.80 (3.46, 4.17)	5.15 (4.07, 6.50)	
Both moderate and vigorous	18.14 (17.23, 19.09)	17.93 (16.98, 18.93)	20.02 (17.69, 22.56)	
Hypertension (%)				< 0.001
No	68.40 (67.29, 69.49)	70.07 (68.99, 71.13)	53.46 (50.36, 56.53)	
Yes	31.60 (30.51, 32.71)	29.93 (28.87, 31.01)	46.54 (43.47, 49.64)	
Diabetes (%)				< 0.001
No	88.29 (87.75, 88.80)	89.42 (88.84, 89.98)	78.13 (76.21, 79.94)	
Yes	11.71 (11.20, 12.25)	10.58 (10.02, 11.16)	21.87 (20.06, 23.79)	
Smoke (%)				< 0.001
Current smokers	18.95 (18.01, 19.92)	18.91 (17.94, 19.93)	19.24 (17.30, 21.35)	
Former smokers	24.94 (23.95, 25.96)	24.34 (23.32, 25.39)	30.29 (27.78, 32.92)	
Never smokers	56.11 (54.80, 57.42)	56.75 (55.40, 58.08)	50.47 (47.59, 53.36)	
Alcohol use (%)				0.014
No	86.81 (85.84, 87.72)	86.49 (85.53, 87.40)	89.64 (87.04, 91.77)	
Yes	13.19 (12.28, 14.16)	13.51 (12.60, 14.47)	10.36 (8.23, 12.96)	
CVDs (%)				< 0.001
No	91.61 (91.10, 92.10)	92.36 (91.83, 92.86)	84.91 (82.91, 86.72)	
Yes	8.39 (7.90, 8.90)	7.64 (7.14, 8.17)	15.09 (13.28, 17.09)	
Conicity index	1.308 (1.305, 1.310)	1.304 (1.301 0.1.306)	1.342 (1.338, 1.347)	< 0.001
Glycohemoglobin (%)	5.63 (5.61, 5.65)	5.60 (5.59, 5.62)	5.85 (5.79, 5.90)	< 0.001
Continued				

Characteristics	Overall (N = 24526)	No KSD history (N = 22140)	KSD history (N = 2386)	P-value
TC (mmol/L)	5.00 (4.98, 5.03)	5.01 (4.99, 5.04)	4.94 (4.88, 5.00)	0.019
Vitamin D intake (mcg)	4.66 (4.58, 4.75)	4.69 (4.60, 4.78)	4.47 (4.25, 4.69)	0.076
Calcium intake (mg)	972.40 (960.85, 983.95)	976.88 (965.04, 988.71)	932.49 (907.78, 957.19)	< 0.001
Water intake (gm)	2960.38 (2924.88, 2995.88)	2962.33 (2926.04, 2998.62)	2942.97 (2870.86, 3015.08)	0.591
Uric acid (mg/dL)	5.41 (5.38, 5.44)	5.39 (5.36, 5.42)	5.61 (5.53, 5.69)	< 0.001

Table 1. Baseline characteristics of participants with or without KSD history, weighted. Data in the table: For continuous variables: survey-weighted mean (95% CI), P-value was by survey-weighted linear regression. For categorical variables: survey-weighted percentage (95% CI), P-value was by survey-weighted Chi-square test.

	Model 1			Model 2			Model 3		
Characteristic	OR	95% CI	P-value	OR	95% CI	P-value	OR	95% CI	P-value
Continuous [a]	1.60	1.50, 1.70	< 0.001	1.33	1.23, 1.44	< 0.001	1.23	1.14, 1.35	< 0.001
Conicity index									
Q1	1.00	-	-	1.00	-	-	1.00	-	-
Q2	1.45	1.19, 1.77	< 0.001	1.17	0.95, 1.44	0.123	1.16	0.95, 1.41	0.159
Q3	2.30	1.96, 2.71	< 0.001	1.60	1.34, 1.90	< 0.001	1.52	1.27, 1.82	< 0.001
Q4	3.03	2.55, 3.61	< 0.001	1.85	1.51, 2.26	< 0.001	1.62	1.32, 1.99	< 0.001
P for trend			< 0.001			< 0.001			< 0.001

Table 2. OR (95% CIs) for KSD based on conicity index, weighted. OR: odds ratio, CI: confidence interval. [a]Each 0.1 unit increase in conicity index. Model 1: Non-adjusted. Model 2: Adjusted for sex, age, race, education, marital status, PIR, BMI, physical activity, smoke, and alcohol use. Model 3: Adjusted for sex, age, race, education, marital status, PIR, BMI, physical activity, smoke, alcohol use, hypertension, diabetes, CVDs, glycohemoglobin, TC, Uric acid, vitamin D intake, calcium intake and water intake.

accounting for 8.0% of the total effect, respectively (Fig. 7B,D). After controlling for RDW, the direct effects on KSD and all-cause mortality were 0.017 (95% CI: 0.010, 0.023) and 0.353 (95% CI: 0.285, 0.421). These results highlight the significant mediating roles of albumin and RDW in the pathways through which the conicity index influences KSD and all-cause mortality.

Discussion

To the best of our knowledge, this study is the first to utilize extensive observational and follow-up data from NHANES 2007–2018 to explore the associations between the conicity index and both the prevalence of KSD and all-cause mortality within a U.S. population. Our findings indicate a strong positive correlation between the conicity index and the occurrence of KSD, a result that is consistent across univariate and multivariate logistic regression models, as well as smoothing spline analyses. In examining the predictive power of abdominal obesity indicators for the risk of kidney stones, the conicity index demonstrated superior predictive ability (AUC = 0.619) compared to traditional measures such as BMI, WC, WHR, BRI, and WHtR. This superior performance may be attributed to the conicity index's more accurate reflection of the distribution and volume of abdominal fat. Consequently, the higher AUC values of the conicity index underscore its potential value in clinical assessments, suggesting that the conicity index may be a more effective tool for predicting the occurrence of kidney stones. Furthermore, elevated conicity index values are significantly associated with increased risks of all-cause mortality among individuals with KSD, as evidenced by both unadjusted and adjusted Cox regression and smoothing spline analyses. Mediation analyses indicate that serum albumin and RDW partly mediate the relationship between the conicity index and both the prevalence of KSD and all-cause mortality. Subgroup analyses highlight that the increased prevalence of KSD associated with the conicity index is particularly evident in males, younger individuals (under 50 years), and participants without diagnosed hypertension or diabetes. Additionally, the positive association between the conicity index and all-cause mortality is notably stronger among those without diagnosed hypertension or diabetes.

Kidney stones, an increasingly serious public health issue, continue to impose a growing burden on healthcare systems. Therefore, identifying modifiable risk factors for adequate prevention and management is crucial. Although prior studies have explored the relationship between obesity and kidney stones, the relationship between conicity index—a measure of abdominal obesity—and both kidney stone prevalence and mortality among these patients has not been extensively studied. Our research provides representative evidence on the relationship between conicity index and both kidney stone disease and all-cause mortality, as well as the partial mediating role of albumin and RDW. We used a large, nationally representative sample and conducted comprehensive statistical analyses to enhance the robustness of our results. Our findings suggest that interventions to reduce abdominal obesity may help decrease the risk of kidney stones and all-cause mortality.

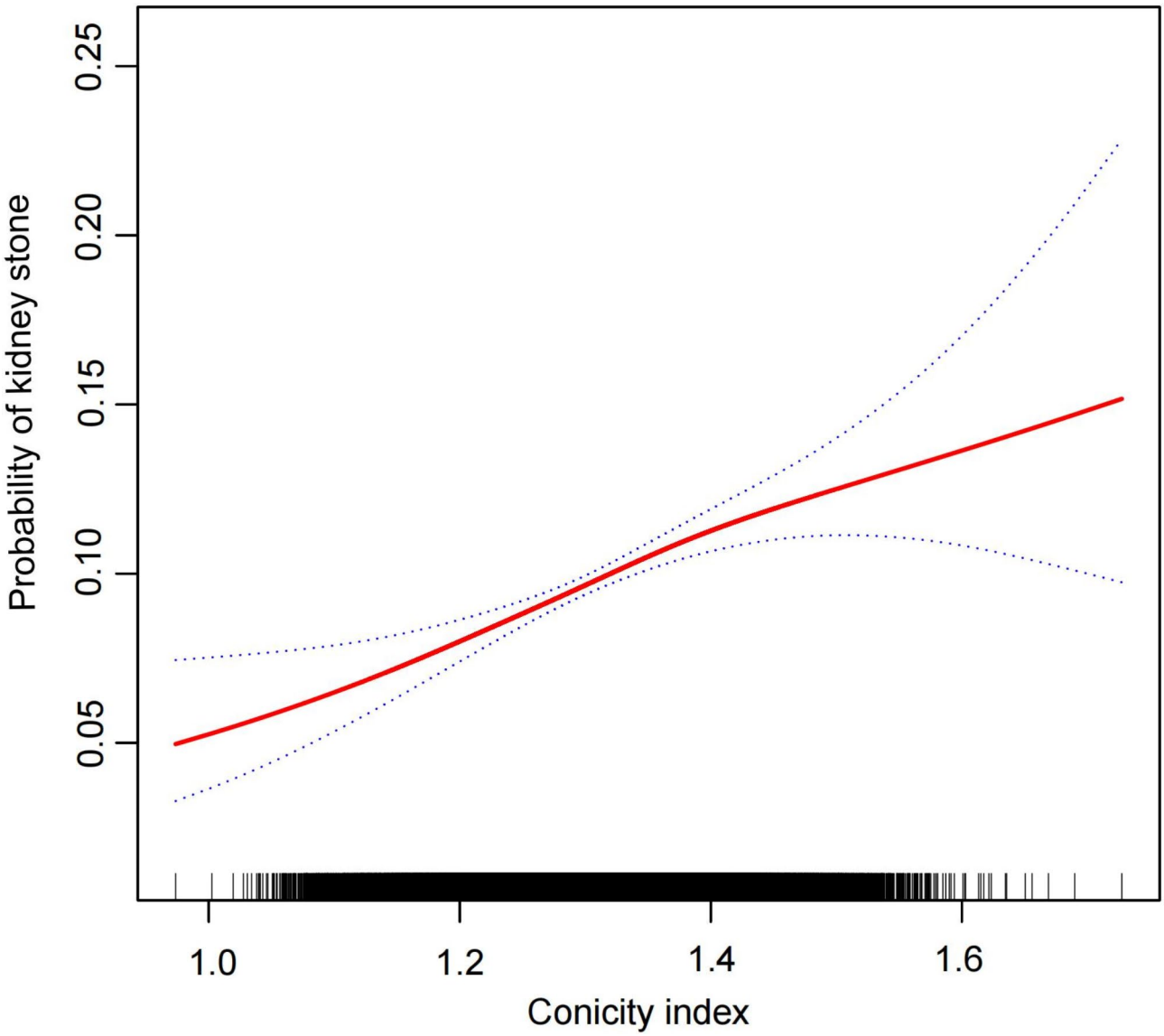

Fig. 2. Smooth curve fitting of the relationship between conicity index and KSD probability. Adjusted for sex, age, race, education, marital status, PIR, BMI, physical activity, smoke, alcohol use, hypertension, diabetes, CVDs, glycohemoglobin, TC, Uric acid, vitamin D intake, calcium intake and water intake.

Our findings align with previous studies that have explored the relationship between obesity and the risk of kidney stones. A cross-sectional study from the Taiwan Biobank demonstrated that various obesity-related indices, including the conicity index, are associated with an increased risk of kidney stones[23]. Similarly, research from Japan[12] and the United States[24] has identified BMI as a significant risk factor for kidney stones in men. Further research by Mao et al. found a positive correlation between the BRI and kidney stones, with diagnostic efficacy surpassing that of BMI[25]. Our study builds on these findings by highlighting the conicity index as an abdominal obesity indicator with even higher diagnostic effectiveness. Ando et al.'s study identified a significant correlation between insulin resistance and an increased risk of kidney stone formation[26]. This association is likely due to the fact that both increased abdominal fat and impaired glucose tolerance are key risk factors for urinary stone development[27,28]. Additionally, research has demonstrated that insulin inhibits renal tubular reabsorption of calcium and promotes the excretion of calcium in urine[29,30]. Given that obesity can induce insulin resistance, this further elevates the risk of calcium stone formation.

Moreover, our findings indicate that the conicity index is associated with an increased risk of all-cause mortality. This association is likely linked to several mechanisms: primarily, the conicity index reflects the accumulation of abdominal fat, which can lead to increased insulin resistance, thrombosis, dyslipidemia, and inflammatory metabolic disturbances[31,32], further elevating the risk of all-cause mortality. Notably, for individuals with KSD, every 0.1 unit increase in the conicity index is associated with a 44% increase in the risk of all-cause mortality after adjustment. This indicates that central obesity is not only related to the prevalence of kidney stones but also to an increased risk of mortality in patients with KSD. For individuals without KSD, each 0.1 unit increase

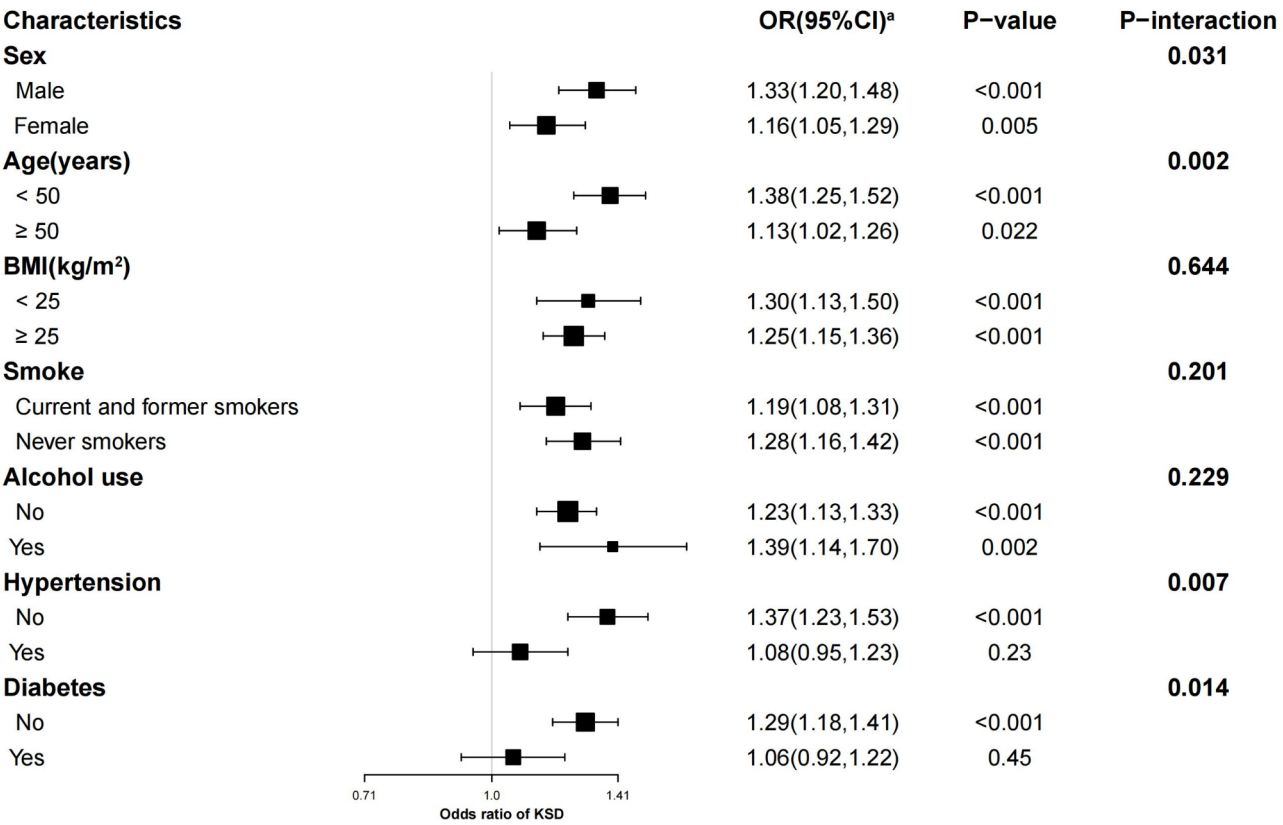

Fig. 3. Subgroup analysis of the association between conicity index and KSD prevalence. Adjusted for sex, age, race, education, marital status, PIR, BMI, physical activity, smoke, alcohol use, hypertension, diabetes, CVDs, glycohemoglobin, TC, Uric acid, vitamin D intake, calcium intake and water intake. [a] OR and 95%CI for each 0.1-unit increase in the conicity index.

in the conicity index increases the risk of all-cause mortality by 53% after adjustment, suggesting that central obesity is a significant predictor of mortality risk, even in populations without kidney stones. Furthermore, our study found that KSD status does not exhibit a significant interaction with the association between the conicity index and all-cause mortality ($p = 0.616$). These findings underscore the independent impact of central obesity assessed by the conicity index on mortality risk and highlight its consistent effects across different health statuses, whether individuals have kidney stones or not. This further emphasizes the importance of managing central obesity, irrespective of an individual's kidney stone status.

Albumin exhibits significant anti-inflammatory, antioxidant, and immunomodulatory functions. Low serum albumin levels may indicate impaired nutritional status; nutritional deficiencies could reduce albumin synthesis in the liver, thereby impairing its anti-inflammatory and immunomodulatory functions[33,34], which in turn increases the risk of kidney stones and all-cause mortality. Additionally, low serum albumin levels can promote increased oxidative stress within the body, damaging tissue cells and exacerbating the development of various chronic diseases[35]. Thus, a decline in albumin levels may affect kidney function and disrupt metabolic status, inflammation levels, and nutritional state, further elevating the risk of kidney stones and all-cause mortality[36]. Studies have shown that RDW significantly impacts the severity and prognosis of end-stage heart failure patients[37]. Many biomarkers associated with heart failure, such as high-sensitivity C-reactive protein, leukocytes, and erythrocyte sedimentation rate, are closely related to RDW[38]. Consequently, high RDW levels are closely linked to the occurrence and prognosis of cardiovascular diseases, and monitoring and adjusting RDW levels could help reduce the risk of all-cause mortality. Further research is needed to explore the relationship between kidney stones and RDW.

Our study possesses evident advantages. Firstly, it is the inaugural study to utilize large-scale NHANES data to evaluate the relationship between the conicity index and both KSD and all-cause mortality risk within the American population. Unlike previous research predominantly employing BMI as the metric for obesity assessment[39], our choice of the conicity index provides a more comprehensive evaluation of abdominal obesity, enabling a more accurate determination of fat distribution. Notably, our data demonstrate that the conicity index significantly outperforms traditional measures such as BMI in predictive capability (AUC = 0.619). Furthermore, in a 10-year community-based follow-up study, the conicity index was shown to have superior predictive efficacy for all-cause mortality among non-cancerous elderly individuals in China, compared to other obesity metrics[40]. Silva et al. also reached similar conclusions[41], affirming the conicity index's exceptional performance. These results not only validate the conicity index as an effective tool for assessing central obesity risks but also pave the

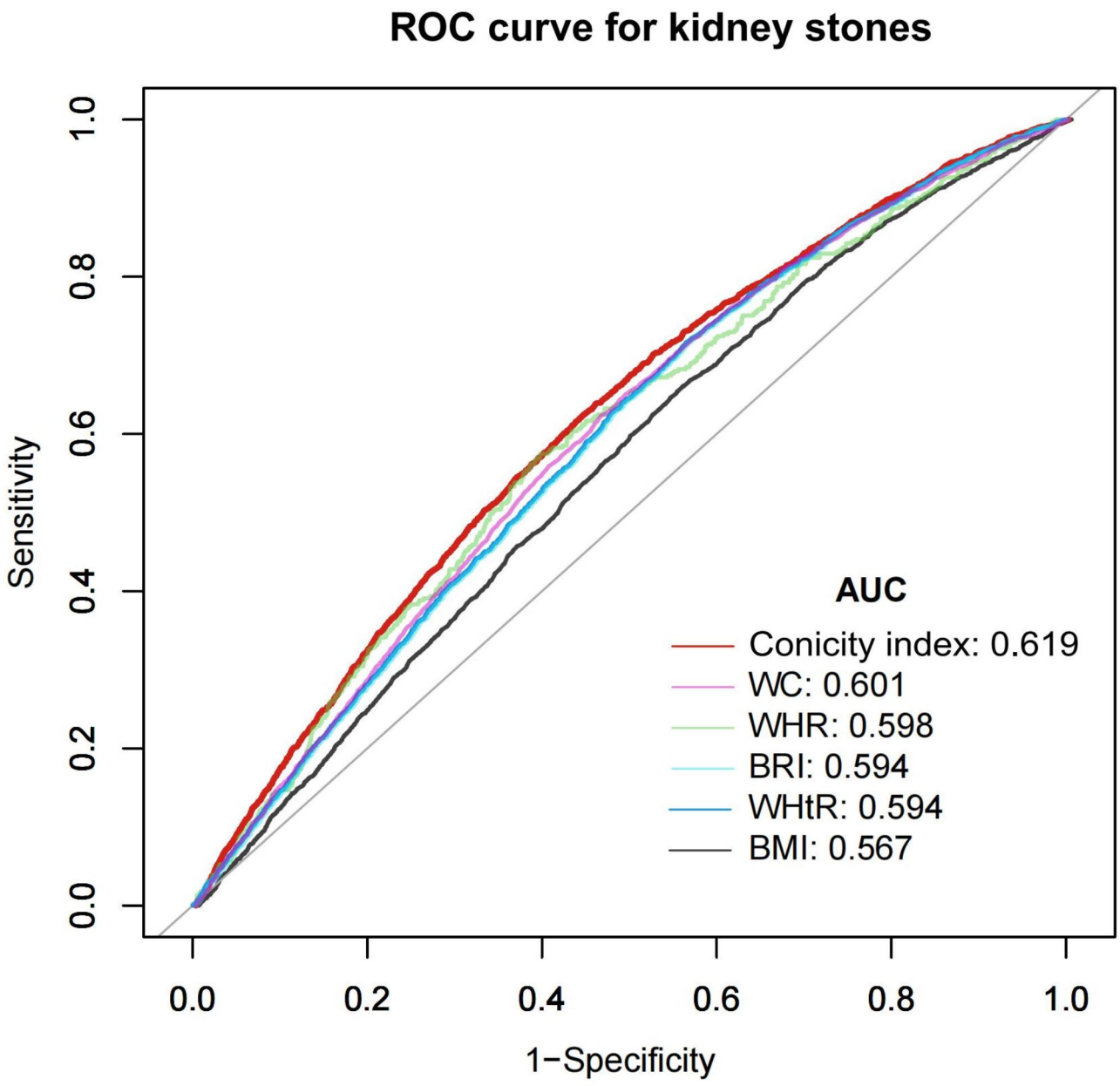

Fig. 4. Diagnostic performance of conicity index and other abdominal obesity indicators on the prevalence of kidney stones.

way for new applications in clinical and public health settings. Our results underscore the critical role of central obesity, assessed through the conicity index, in influencing the risk of kidney stones and all-cause mortality. Therefore, healthcare professionals should enhance their understanding of the link between central obesity and kidney stones and advocate for effective preventive measures such as healthy eating, appropriate exercise, and maintaining an ideal conicity index to reduce the risk of these diseases.

However, our study also has some limitations. Firstly, the cross-sectional study design restricts the exploration of the causal relationship between the conicity index and kidney stones, necessitating further extensive prospective cohort studies to assess their correlation. Additionally, the series of mediation analyses we conducted are observational in nature and do not imply causation. However, mediation analysis can still provide insights into potential causal mechanisms, although the definitive causal relationships require further validation through longitudinal studies. Furthermore, the kidney stone data in the study is derived from self-reported questionnaire designs, with outcomes self-reported by participants, possibly leading to inaccuracies due to recall bias. Although we adjusted for multiple covariates in the multivariate model, including demographic factors, smoking and drinking status, diabetes, hypertension, and blood laboratory tests, there might still be other unmeasured or unknown confounding factors influencing the relationship between the conicity index and both KSD and all-cause mortality. To mitigate the impact of these limitations, we also conducted subgroup

Characteristic	Model 1			Model 2			Model 3		
	HR	95% CI	P-value	HR	95% CI	P-value	HR	95% CI	P-value
All participants									
Continuous[a]	2.13	1.98, 2.29	<0.001	1.75	1.59, 1.93	<0.001	1.51	1.36, 1.67	<0.001
Conicity index									
Q1	1.00	-	-	1.00	-	-	1.00	-	-
Q2	1.83	1.45, 2.31	<0.001	1.55	1.16, 2.06	0.003	1.42	1.08, 1.88	0.013
Q3	3.38	2.68, 4.25	<0.001	2.34	1.72, 3.19	<0.001	1.99	1.48, 2.69	<0.001
Q4	6.13	4.91, 7.66	<0.001	3.42	2.50, 4.68	<0.001	2.51	1.84, 3.43	<0.001
P for trend			<0.001			<0.001			<0.001
KSD history									
Continuous[a]	1.94	1.66, 2.27	<0.001	1.70	1.34, 2.17	<0.001	1.44	1.14, 1.82	0.002
Conicity index									
Q1	1.00	-	-	1.00	-	-	1.00	-	-
Q2	3.56	1.98, 6.41	<0.001	2.70	1.45, 5.03	0.002	2.41	1.25, 4.63	0.009
Q3	6.28	3.66, 10.76	<0.001	4.39	2.22, 8.69	<0.001	3.62	1.88, 6.99	<0.001
Q4	9.49	5.85, 15.41	<0.001	5.89	3.00, 11.57	<0.001	4.33	2.22, 8.45	<0.001
P for trend			<0.001			<0.001			<0.001
No KSD history									
Continuous[a]	2.12	1.96, 2.30	<0.001	1.76	1.59, 1.95	<0.001	1.53	1.37, 1.70	<0.001
Conicity index									
Q1	1.00	-	-	1.00	-	-	1.00	-	-
Q2	1.72	1.35, 2.20	<0.001	1.47	1.10, 1.97	0.009	1.36	1.02, 1.82	0.036
Q3	3.11	2.47, 3.92	<0.001	2.19	1.64, 2.93	<0.001	1.87	1.41, 2.50	<0.001
Q4	5.78	4.58, 7.29	<0.001	3.26	2.40, 4.43	<0.001	2.42	1.78, 3.29	<0.001
P for trend			<0.001			<0.001			<0.001

Table 3. HR (95% CIs) for all-cause mortality based on conicity index, weighted. HR: hazard ratio, CI: confidence interval. [a]Each 0.1 unit increase in conicity index. Model 1: Non-adjusted. Model 2: Adjusted for sex, age, race, education, marital status, PIR, BMI, physical activity, smoke, and alcohol use. Model 3: Adjusted for sex, age, race, education, marital status, PIR, BMI, physical activity, smoke, alcohol use, hypertension, diabetes, CVDs, glycohemoglobin, TC, Uric acid, vitamin D intake, calcium intake and water intake.

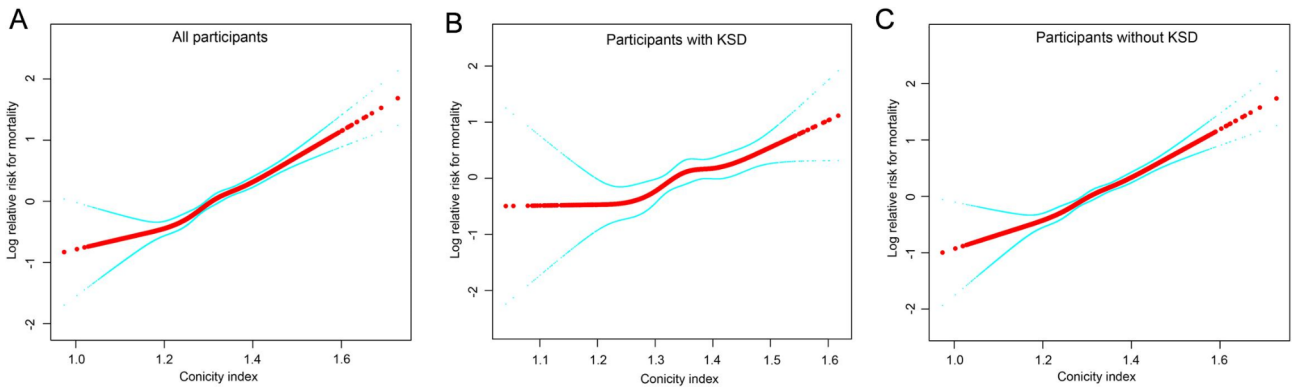

Fig. 5. Smooth curve fitting of the relationship between conicity index and all-cause mortality, separately in all participants (**A**), participants with KSD (**B**), and those without KSD (**C**). Adjusted for sex, age, race, education, marital status, PIR, BMI, physical activity, smoke, alcohol use, hypertension, diabetes, CVDs, glycohemoglobin, TC, Uric acid, vitamin D intake, calcium intake and water intake.

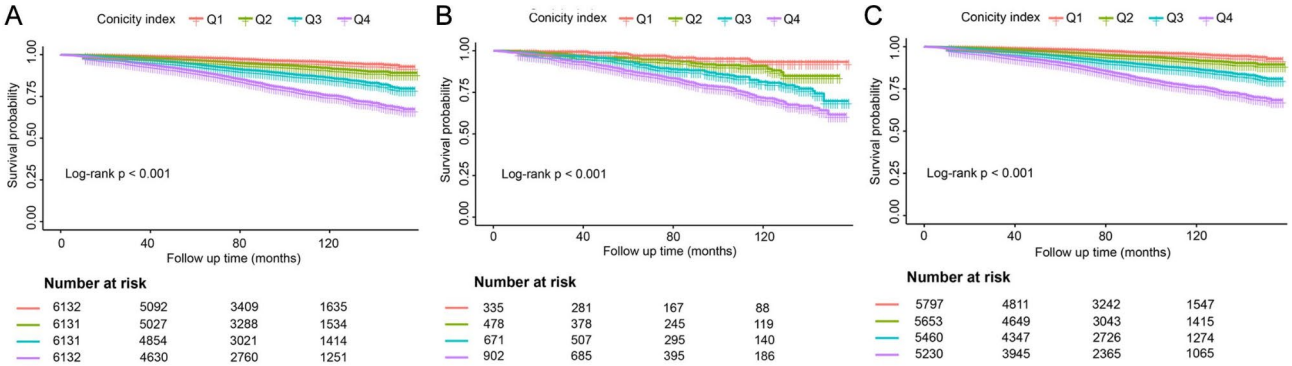

Fig. 6. Kaplan–Meier analysis of all-cause mortality by quartiles of conicity index (Q1-Q4) in (**A**) all participants, (**B**) participants with KSD, and (**C**) participants without KSD.

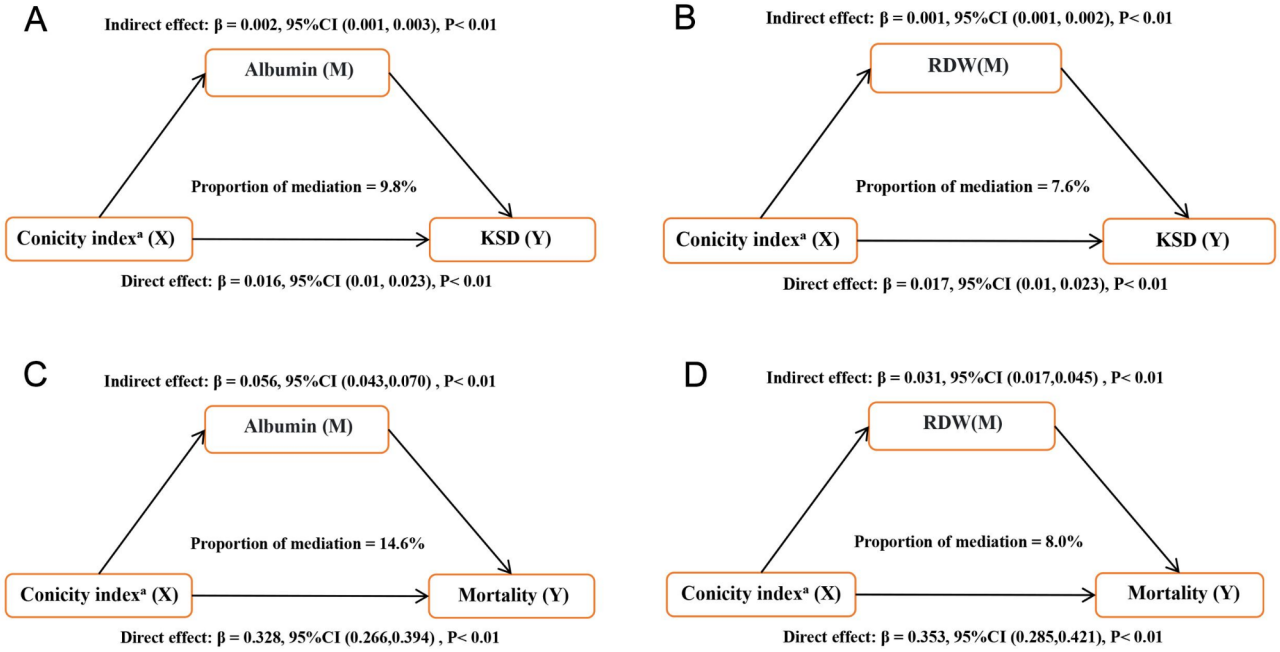

Fig. 7. Mediation analysis of the relationships between conicity index and KSD mediated by albumin (**A**) and RDW (**B**), and the relationships between conicity index and all-cause mortality mediated by albumin (**C**) and RDW (**D**). Adjusted for sex, age, race, education, marital status, PIR, BMI, physical activity, smoke, alcohol use, hypertension, diabetes, CVDs, glycohemoglobin, TC, Uric acid, vitamin D intake, calcium intake and water intake. KSD, kidney stone disease. RDW, red cell distribution width. [a] Each 0.1 unit increase in conicity index.

analyses across different populations and further assessed the interactions between these associations in various subgroups.

Conclusion

A higher conicity index is significantly positively correlated with both the prevalence of KSD and all-cause mortality rates. Additionally, serum albumin and RDW partially mediate these associations. Therefore, effectively managing central obesity, as measured by the conicity index, could substantially lessen the health burdens related to KSD and mortality. Nevertheless, further research is essential to corroborate our findings.

Data availability

The datasets utilized in this study are publicly accessible. Interested parties can access the data through the National Health and Nutrition Examination Survey (NHANES) website at https://www.cdc.gov/nchs/nhanes/index.htm. For additional information or inquiries, please contact the corresponding author.

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Author contributions
XD led the project design, created visuals, wrote the first draft, and managed the data. YC conducted the research, developed the methods, and helped write the first draft. YH reviewed and edited the manuscript, and also obtained funding. All authors carefully read and approved the final manuscript.

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Declarations

Competing interests
The authors declare no competing interests.

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