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Association between conicity index and frailty in older Americans: the NHANES cross-sectional study, 2007–2018

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This study utilized NHANES data from 2007 to 2018 to investigate the correlation between frailty and the Conicity Index (CI) in individuals aged 60 and above in the United States. The study used NHANES data from 2007 to 2018.CI was calculated as CI = wc / [0.109 × sqrt(bw / Height)]. Frailty was assessed by the frailty index (≥ 0.25). Weighted multivariate logistic regression analysis, subgroup analyses, and interaction tests were used to investigate the connection between CI and the prevalence of frailty. Generalized additive modeling (GAM) was employed to address any non-linear patterns, and the predictive capability of CI for frailty was evaluated by receiver operating characteristic (ROC) analysis. With a 69% rise in the prevalence of frailty for every 0.1 unit increase in the fully adjusted model, the results demonstrated a strong and positive relationship between CI and frailty prevalence (OR: 1.69, 95% CI: 1.53,1.86; P < 0.001). When CI was categorized, the group with the highest CI had a significantly higher prevalence of frailty than the group with the lowest CI (OR = 2.79, 95% CI: 2.22,3.51; P < 0.001). The association between CI and prevalence of frailty was significant in all subgroups. In addition, statistically significant interactions were present in most subgroups. When the CI > reached 1.35, the GAM model demonstrated a threshold effect and a significant nonlinear connection, with a 105% rise in the prevalence of frailty for every 0.1 unit increase in CI. In the male group, CI was a significantly greater indicator of the prevalence of frailty than both BMI and WC. According to this study, frailty in older persons is substantially correlated with a higher CI. Although greater confirmation in large-scale prospective research is required, this study indicates that increased CI is a more reliable predictor of the prevalence of frailty in older men and is significantly linked with its occurrence.

Keywords Conicity index, Obesity, Cross-sectional study, Frailty, NHANES

The state of frailty, which is characterized by the deterioration of several physiological systems, greatly raises the risk of falls, incapacity, hospitalization, and even death[1]. As the global population ages at an accelerated rate, frailty is becoming particularly prominent in the elderly population[2]. Understanding the metabolic basis of frailty is becoming increasingly important to identify modifiable risk factors and develop targeted interventions[3]. It is commonly acknowledged that one of the main risk factors for frailty is obesity. However, traditional assessments of body fat have mostly relied on metrics such as waist circumference (WC) or body mass index (BMI)[4] but may have limitations when assessing the elderly population. These methods do not accurately reflect the distribution of body fat, the distribution and quality of which may have a greater impact on the development of frailty[5].

The CI, a new obesity-related index, is different from the traditional BMI in that CI combines weight, waist circumference, and height to more accurately reflect the distribution of fat, especially the effect of abdominal fat[6]. According to previous research, CI exhibits high sensitivity in predicting risk for a number of illnesses, including metabolic diseases[7], hypertension[8], gallstones[9], and urinary incontinence in women[10]. In addition, studies have found a linear relationship between CI and mortality risk, suggesting that a high CI may increase mortality[11], which further supports the potential value of CI in health surveillance and risk assessment.

While numerous studies have demonstrated a correlation between obesity and frailty, research addressing the relationship between CI and frailty remains limited. Therefore, this study aims to improve our understanding of CI's role in frailty screening and offer new support for early intervention in the elderly population by evaluating

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its potential role in predicting frailty prevalence and examining its applicability in older U.S. adults using data from the National Health and Nutrition Examination Survey (NHANES) from 2007 to 2018.

Materials and methods

Database sources and sample selection

The NHANES is a nationwide cross-sectional research that assesses the general health and nutritional status of noninstitutionalized U.S. adults using stratified multistage random sampling, which is carried out by the National Center for Health Statistics (NCHS). Selected data from NHANES between 2007 and 2018 were used for the analysis of this study. First, information from 59,842 NHANES participants from 2007 to 2018 was taken into account. The final sample consisted of 8,748 participants, excluding 47,932 persons younger than 60 years of age, 2,649 persons with unreliable frailty index assessments, 350 persons with missing or outlier CI data, and 163 persons with missing covariates (Fig. 1). Informed consent forms were signed by all survey respondents, and the NHANES data were made publicly available.

Assessment of frailty

A deficit accumulation model was used to measure frailty, and in order to be eligible, individuals had to answer at least 91% of the 49 questions on the Frailty Index (FI). The 49 diagnostic criteria that make up the FI encompass topics including cognitive function, physical performance, capacity to carry out everyday tasks, chronic illnesses, health status, and laboratory testing. The final FI is calculated by dividing the total of the scores by the number of items[12,13]. Each criteria is rated based on severity, with 0 denoting no frailty and 1 denoting severe frailty. A FI value of 0.25 or greater than 14 is considered frail[14]. The complete set of criteria is given in Supplementary Table 1.

Assessment of CI

Thorough training was provided to all NHANES employees to guarantee measurement accuracy and uniformity. The exposure variable, CI, was computed as follows: $CI = wc / [0.109 \times sqrt(bw / Height)]$, with waist circumference and height in meters, and body weight in kilograms[6]. Both continuous and categorical variables might be used to examine CI data. The CI values were analyzed by dividing them into four groups (first quartile: $0.97 < CI \leq 1.31$; second quartile: $1.31 < CI \leq 1.36$; third quartile: $1.36 < CI \leq 1.41$; fourth quartile: $1.41 < CI \leq 1.73$).

Covariates

The study controlled for a number of well-known covariates, such as age, gender, race, education level, marital status, PIR, diastolic and systolic blood pressure, energy intake, the Healthy Eating Index 2015 (HEI-2015),

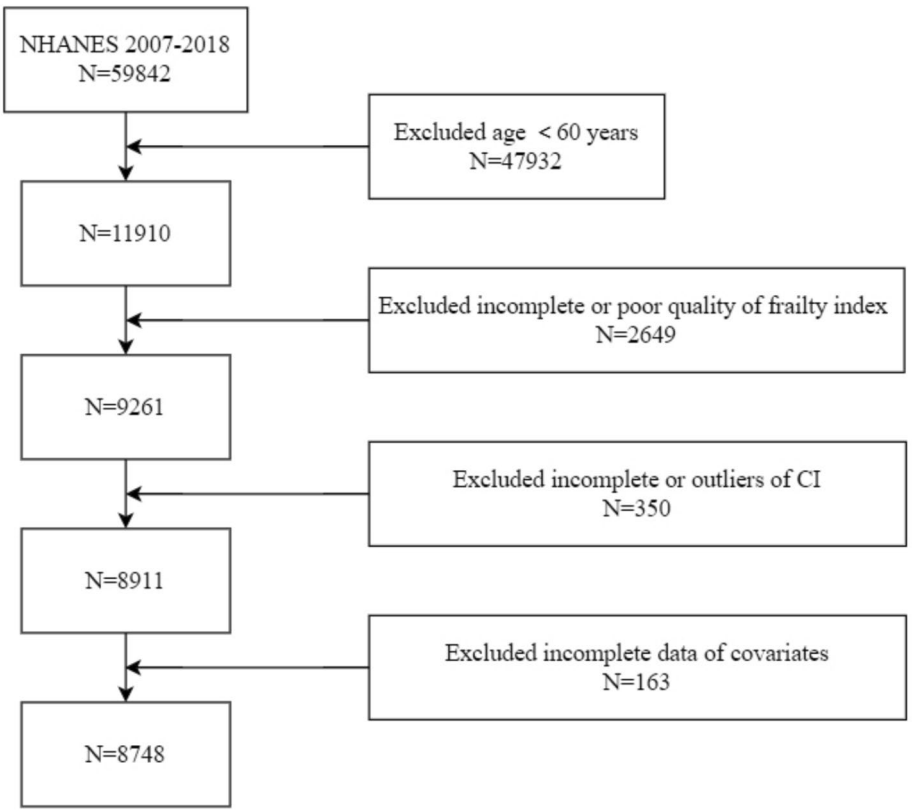

Fig. 1. Flowchart of the population selection from NHANES.

smoking, alcohol use, and physical activity, in order to account for confounding variables. In addition, chronic diseases such as hypertension, high cholesterol, diabetes, cardiovascular disease, chronic obstructive pulmonary disease (COPD), and chronic kidney disease (CKD) were also potential factors affecting frailty. PIR ≤ 1.3, 1.3 < PIR ≤ 3.5, and PIR > 3.5 were used to classify specific income levels; smoking was defined as 100 cigarettes or more during one's lifetime; and alcohol use was divided into five categories based on current drinking status: never, former, heavy, moderate, and mild drinking[15,16]. Detailed categorization criteria are shown in Supplementary Table 2. Blood pressure was estimated by averaging at least three consecutive standard measurements. Dietary information was gathered on the first day of the 24-h dietary recall trial. A person's dietary compliance with the Dietary Guidelines for Americans is assessed by the HEI-2015[17]. Values vary from 0 to 100, with higher scores denoting higher-quality food and healthier eating practices.

Statistical analysis

Each statistical analysis took into account the complex sampling design of NHANES and applied the appropriate sampling weights. To avoid excessively large effect sizes, we created new data with a tenfold CI for the analysis. Interpolated missing data for PIR, energy intake, HEI-2015, and alcohol use using the random forest method (missing values did not exceed 15%). Continuous variables are shown as mean ± standard error (SE), whilst categorical data are presented as weighted percentages. Group differences were evaluated at baseline using t-tests and weighted chi-square. The three weighted multivariate logistic regression models that were used to examine the relationship between CI and frailty were Model 1 (unadjusted), Model 2 (adjusted for age, gender, race, and education level), and Model 3 (further adjusted for variables such as marital status, PIR, smoking, alcohol use, physical activity, SBP, DBP, HEI-2015, and energy intake). While threshold effects and turning points were examined using linear regression models, potential nonlinear connections were assessed using GAM. Furthermore, interaction tests and subgroup analysis have been performed out. ROC analysis was used to examine the predictive power of CI, BMI, and WC for frailty. DeLong tests were used to look for statistically significant changes in the ROC analysis findings. Sensitivity analyses consisted, among other things, of removing all missing covariates and further adjusting for hypertension, high cholesterol, cardiovascular disease, diabetes, COPD, CKD, cholesterol-lowering, and antidiabetic medication use. P-values below 0.05 were regarded as statistically significant. All statistical analyses were conducted using Empower States (version 4.2) and R software (version 4.2).

Results

Baseline characteristics of participants

Table 1 displays the overall demographics of the 8,748 participants in the study, whose mean age was 69.48 ± 6.81 years.The sample was very well divided, with 49.94% of the participants being female and 50.06% being male. 13.57 ± 0.80 was the mean CI. As CI grew, the prevalence of frailty rose noticeably. The basic characteristics of the groups differed significantly depending on whether they were frailty or not.

Multiple logistic regression analysis

Table 2 provides a summary of the weighted multivariate logistic regression analysis's results. For every 0.1 unit increase in CI (95% CI: 1.66,2.00; P < 0.001), the prevalence of frailty rose 1.82 times in model 1 (unadjusted); in model 2 (adjusted for age, sex, race, and education), the OR was 1.91 (95% CI: 1.73,2.11; P < 0.001). The prevalence of frailty increased 69% in fully adjusted model 3 for every 0.1 unit rise in CI (OR: 1.69, 95% CI: 1.53,1.86; P < 0.001). Additionally, Table 2 shows that when CI was classified, the prevalence of frailty was significantly higher in the group with the greatest CI than in the group with the lowest CI (OR = 2.79, 95% CI: 2.22,3.51; P < 0.001).

Nonlinear analysis

The association between CI and the prevalence of frailty was further assessed using GAM, and the findings showed a significant nonlinear connection (Fig. 2, Table 3). Segmented regression analysis provided more evidence for the presence of a threshold effect. Furthermore, a threshold effect and a significant nonlinear association were seen in both males and females.

Subgroup analysis

Subgroup analyses were carried out to investigate the association in various groups, accounting for factors such age, gender, race, education, marital status, BMI, PIR, BMI, HEI-2015, physical activity, smoking, and alcohol use. Further supporting the idea that CI is a risk factor for frailty development in older Americans is the analysis's findings, which revealed a significant correlation between CI and the prevalence of frailty in all subgroups with statistically significant interactions in the majority of subgroups (Table 4).

Results of the subgroup analysis were adjusted for all covariates except the effect modifier.

Sensitivity analysis

A number of sensitivity analyses were performed to ensure the accuracy of the findings. These included deleting all missing covariates and adjusting for hypertension, high cholesterol, diabetes, cardiovascular disease, COPD, CKD, cholesterol-lowering, and antidiabetic medication use. Good stability of the data was indicated by the sensitivity analyses, which continuously revealed a substantial connection between CI and the prevalence of frailty (Table 5).

Characteristics	Total (n = 8748)	Frailty NO(n = 5879)	Frailty YES(n = 2869)	P value
Age (years)	69.48 ± 6.81	68.92 ± 6.66	70.63 ± 6.97	< 0.001
Gender %				< 0.001
Female	4369 (49.94)	2744 (46.67)	1625 (56.64)	
Male	4379 (50.06)	3135 (53.33)	1244 (43.36)	
Race %				< 0.001
Mexican American	1045 (11.95)	689 (11.72)	356 (12.41)	
Other hispanic	927 (10.60)	621 (10.56)	306 (10.67)	
Non-hispanic white	4278 (48.90)	2870 (48.82)	1408 (49.08)	
Non-hispanic black	1785 (20.40)	1167 (19.85)	618 (21.54)	
Other Race	713 (8.15)	532 (9.05)	181 (6.31)	
Education level %				< 0.001
Less than 9th grade	1230 (14.06)	732 (12.45)	498 (17.36)	
9-11th grade	1177 (13.45)	700 (11.91)	477 (16.63)	
High school graduate	2081 (23.79)	1352 (23.00)	729 (25.41)	
Some college or AA degree	2369 (27.08)	1588 (27.01)	781 (27.22)	
College graduate or above	1891 (21.62)	1507 (25.63)	384 (13.38)	
Marry %				< 0.001
Married/Living with partner	5238 (59.88)	3751 (63.80)	1487 (51.83)	
Widowed/Divorced/Separated	3053 (34.90)	1829 (31.11)	1224 (42.66)	
Never married	457 (5.22)	299 (5.09)	158 (5.51)	
PIR %				< 0.001
Low income	2433 (27.81)	1364 (23.20)	1069 (37.26)	
Med income	3677 (42.03)	2398 (40.79)	1279 (44.58)	
High income	2638 (30.16)	2117 (36.01)	521 (18.16)	
Alcohol use %				< 0.001
Never	1399 (15.99)	889 (15.12)	510 (17.78)	
Former	2024 (23.14)	1152 (19.60)	872 (30.39)	
Mild	3741 (42.76)	2696 (45.86)	1045 (36.42)	
Moderate	909 (10.39)	690 (11.74)	219 (7.63)	
Heavy	675 (7.72)	452 (7.69)	223 (7.77)	
Smoking %				< 0.001
No	4324 (49.43)	3042 (51.74)	1282 (44.68)	
Yes	4424 (50.57)	2837 (48.26)	1587 (55.32)	
Physical activity %				< 0.001
Never	5179 (59.20)	3068 (52.19)	2111 (73.58)	
Moderate	2732 (31.23)	2086 (35.48)	646 (22.52)	
Vigorous	837 (9.57)	725 (12.33)	112 (3.90)	
BMI (Kg/m^2)	29.15 ± 6.09	28.21 ± 5.29	31.09 ± 7.09	< 0.001
WC (cm)	102.42 ± 14.61	100.19 ± 13.39	106.97 ± 15.90	< 0.001
SBP (mmHg)	133.80 ± 19.94	133.56 ± 19.32	134.31 ± 21.15	0.095
DBP (mmHg)	67.73 ± 14.20	68.92 ± 13.84	65.31 ± 14.61	< 0.001
HEI-2015	54.46 ± 11.49	55.38 ± 11.71	52.56 ± 10.78	< 0.001
Energy (kcal)	1839.32 ± 780.65	1871.30 ± 775.32	1773.79 ± 787.55	< 0.001
CI	13.57 ± 0.80	13.46 ± 0.77	13.80 ± 0.81	< 0.001

Table 1. The clinical characteristics of participants. Continuous variables were summarized using means with SE, and categorical variables were presented as weighted percentages. *BMI* body mass index, *WC* waist circumference, *SBP* systolic blood pressure, *DBP* diastolic blood pressure, *CI* conicity index, *PIR* income to poverty ratio.

ROC analysis

ROC analysis was used to evaluate the predictive power of CI, BMI, and WC for the prevalence of frailty. The findings indicated that the three did not significantly differ from the whole population, and the predictive ability was poorly demonstrated in the female population. However, when it came to predicting the prevalence of frailty in the male population, CI performed noticeably better than BMI and WC(Fig. 3, Table 6).

	OR[a](95%CI[b])P-value		
	Model 1[c]	Model 1[d]	Model 1[e]
Continuous	1.82 (1.66,2.00)	1.91 (1.73,2.11)	1.69 (1.53,1.86)
P for trend	< 0.001	< 0.001	< 0.001
Categories			
Tertile 1	Reference	Reference	Reference
Tertile 2	1.32 (1.09,1.60)	1.32 (1.08,1.61)	1.20 (0.97,1.47)
	0.006	0.008	0.092
Tertile 3	1.61 (1.32,1.97)	1.71 (1.40,2.09)	1.41 (1.14,1.73)
	< 0.001	< 0.001	0.002
Tertile 4	3.26 (2.67,3.99)	3.60 (2.87,4.51)	2.79 (2.22,3.51)
	< 0.001	< 0.001	< 0.001
P for trend	< 0.001	< 0.001	< 0.001

Table 2. Association between CI and frailty. OR[a], odds ratio; 95% CI[b], 95% confidence interval; Model1[c], adjusted for non covariates; Model2[d], adjusted for age, gender, race, and education; Model3[e], further adjusted for marry, poverty income ratio, smoking, alcohol use, systolicblood pressure, diastolic blood pressure, physical activity, healthy eating index-2015 and energy intake.

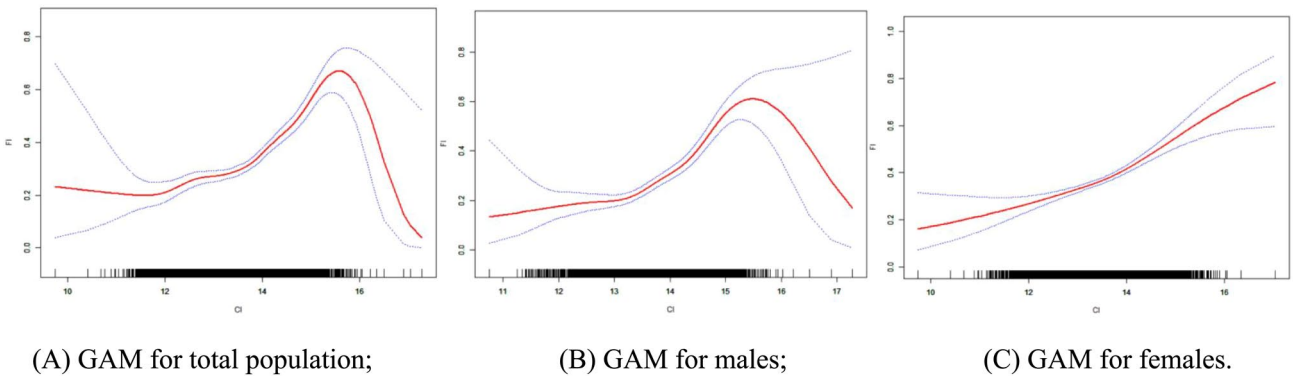

Fig. 2. Generalized additive regression.

	OR[a](95%CI[b])P-value		
	Total	Females	Males
Segmented model			
Turning point (K)	13.53	13.84	13.20
< K OR 1	1.24 (1.09, 1.41)	1.30 (1.14, 1.48)	1.08 (0.79, 1.48)
	0.001	< 0.001	0.633
> K OR 2	2.05 (1.83, 2.30)	1.90 (1.54, 2.35)	2.23 (1.95, 2.55)
	< 0.001	< 0.001	< 0.001
OR 2—1	1.66 (1.35, 2.03)	1.46 (1.09, 1.96)	2.06 (1.40, 3.04)
	< 0.001	0.012	< 0.001
Likelihood ratio test	< 0.001	0.011	< 0.001

Table 3. Segmented regression results. OR[a], odds ratio; 95% CI[b], 95% confidence interval.

Discussion

This study assessed the relationship between CI and frailty risk in US seniors aged 60 and above using NHANES data from 2007–2018. The results showed a significant and independent correlation between a higher prevalence of frailty and CI. Frailty prevalence increased by 69% for every 0.1 unit increase in CI in fully adjusted models. The group with the greatest CI had a significantly higher prevalence of frailty than the group with the lowest CI (OR = 2.79, 95% CI: 2.22,3.51; P < 0.001). Through GAM analysis, it was clarified that there was a nonlinear relationship between CI and frailty, with a 105% increase in frailty risk for every 0.1 unit increase in CI when CI > 1.35. CI considerably surpassed BMI and WC in predicting the prevalence of frailty in the male population,

Subgroup	N	HR (95% CI)	P-value	P for interaction
Age				0.566
≤75	6571	1.67 (1.54,1.8)	<0.001	
>75	2177	1.60 (1.43,1.8)	<0.001	
Gender				0.002
Famale	4369	1.50 (1.38,1.63)	<0.001	
Male	4379	1.86 (1.68,2.06)	<0.001	
Race				<0.001
Mexican American	1045	1.44 (1.18,1.75)	<0.001	
Other Hispanic	927	1.50 (1.24,1.82)	<0.001	
Non-Hispanic White	4278	1.60 (1.46,1.76)	<0.001	
Non-Hispanic Black	1785	1.66 (1.45,1.90)	<0.001	
Other Race	713	2.88 (2.15,3.84)	<0.001	
Education level				0.021
Less than 9th grade	1230	1.32 (1.12,1.55)	0.001	
9-11th grade	1177	1.48 (1.26,1.74)	<0.001	
High school graduate	2081	1.75 (1.54,1.98)	<0.001	
Some college or AA degree	2369	1.79 (1.59,2.01)	<0.001	
College graduate or above	1891	1.69 (1.45,1.98)	<0.001	
Marry				0.013
Married/Living with Partner	5238	1.78 (1.63,1.95)	<0.001	
Widowed/Divorced/Separated	3053	1.53 (1.39,1.69)	<0.001	
Never married	457	1.31 (1.03,1.67)	0.026	
PIR				0.048
Low income	2433	1.46 (1.31,1.64)	<0.001	
Med income	3677	1.71 (1.55,1.88)	<0.001	
High income	2638	1.78 (1.55,2.03)	<0.001	
HEI-2015				0.286
≤60	6147	1.61 (1.49,1.73)	<0.001	
>60	2601	1.74 (1.53,1.97)	<0.001	
BMI				0.009
≤25	2180	1.32 (1.15,1.52)	<0.001	
>25	6568	1.63 (1.50,1.76)	<0.001	
Smoking				0.958
No	4324	1.64 (1.50,1.80)	<0.001	
Yes	4424	1.64 (1.50,1.79)	<0.001	
Alcohol use				0.033
Never	1399	1.46 (1.27,1.69)	<0.001	
Former	2024	1.59 (1.40,1.80)	<0.001	
Mild	3741	1.81 (1.63,2.02)	<0.001	
Moderate	909	1.38 (1.13,1.68)	<0.001	
Heavy	675	1.86 (1.47,2.36)	<0.001	
Physical activity				0.370
Never	5179	1.65 (1.53,1.78)	<0.001	
Moderate	2732	1.56 (1.38,1.76)	<0.001	
Vigorous	837	1.92 (1.46,2.51)	<0.001	

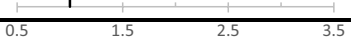

Table 4. Segmented regression results.

according to the results of the ROC curve study, which further demonstrated the advantages of applying CI in differentiating high-risk populations. It should be noted that the absolute differences in AUC values among the three were relatively small. Therefore, the clinical or practical significance of this difference remains unclear and needs to be further validated in larger samples and multicenter studies. The current results suggest that CI has some potential as an indicator of abdominal fat distribution, but it is not yet sufficient to replace existing commonly used indicators, and future studies should focus on its practical value in different populations and specific health outcomes. Subgroup and sensitivity analyses were also performed in this study to increase the

	OR[a] (95% CI[b]) P-value	
	Model 4[c]	Model 5[d]
Continuous	1.63 (1.44,1.83)	1.04 (1.02,1.06)
P for trend	< 0.001	< 0.001
Categories		
Tertile 1	Reference	Reference
Tertile 2	1.20 (0.92,1.56)	1.46 (0.90,2.37)
	0.179	0.124
Tertile 3	1.40 (1.07,1.84)	1.23 (0.77,1.97)
	0.014	0.384
Tertile 4	2.52 (1.89,3.37)	2.03 (1.26,3.27)
	< 0.001	0.003
P for trend	< 0.001	0.008

Table 5. Further adjustment for covariates, disease, and medication conditions. OR[a]: odds ratio; 95% CI[b]: 95% confidence interval; Model 4[c]: further adjustment for missing covariates; Model 5[d]: further adjustment for hypertension, high cholesterol, diabetes, cardiovascular disease, chronic obstructive pulmonary disease, chronic kidney disease, use of cholesterol-lowering and anti-diabetic drugs.

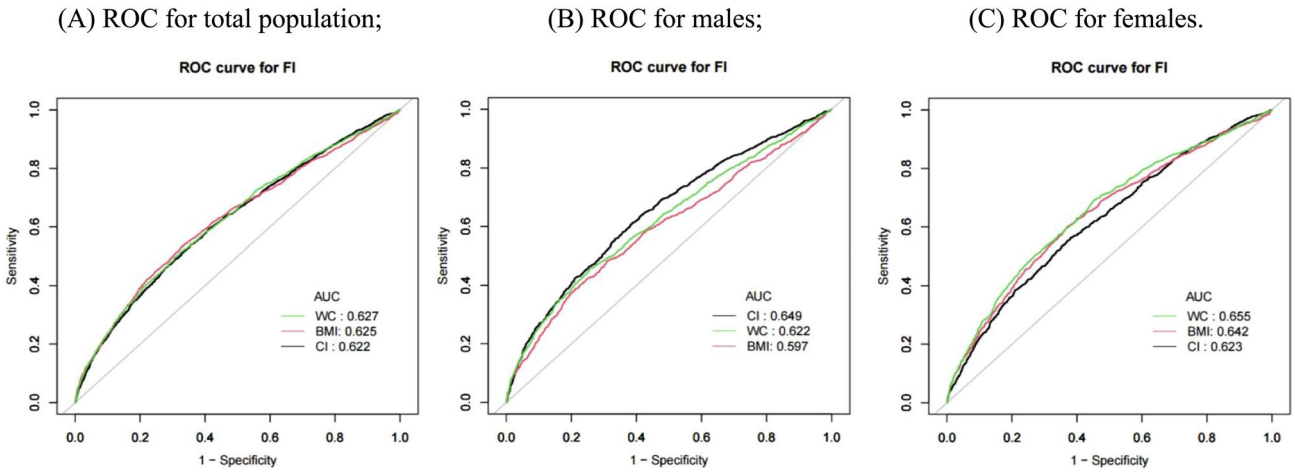

Fig. 3. ROC curve of CI, BMI, and WC.*CI*, conicity index, *BMI,* body mass index, *WC*, waist circumference.

	Variable	AUC (95% CI)	Threshold	Specificity	Sensitivity	Youden Index	P value
Total	CI	0.62 (0.61,0.63)	13.85	0.69	0.49	0.18	-
	BMI	0.62 (0.61,0.64)	29.85	0.67	0.53	0.20	0.697
	WC	0.63 (0.61,0.64)	106.15	0.69	0.50	0.19	0.341
Males	CI	0.65 (0.63,0.67)	13.80	0.61	0.61	0.22	-
	BMI	0.60 (0.58,0.62)	31.39	0.79	0.39	0.18	< 0.001
	WC	0.62 (0.60,0.64)	110.25	0.74	0.46	0.20	< 0.001
Females	CI	0.62 (0.61,0.64)	13.60	0.65	0.54	0.19	-
	BMI	0.64 (0.63,0.66)	29.41	0.63	0.60	0.23	0.050
	WC	0.66 (0.64,0.67)	97.55	0.55	0.69	0.24	< 0.001

Table 6. ROC analysis results. *CI*, conicity index, *BMI*, body mass index, *WC*, waist circumference.

robustness of the findings. After removing the missing covariates, hypertension, high cholesterol, cardiovascular disease, diabetes, COPD, CKD, cholesterol-lowering, and antidiabetic medication use, there were no significant associations between CI and the prevalence of frailty, which demonstrated the strong stability of the study results. In subgroup analyses, the association between CI and prevalence of frailty was significant in all subgroups, with statistically significant interactions in most subgroups, suggesting that CI has good applicability and predictive power across a wide range of older populations. Subgroup analyses showed a higher prevalence of frailty in men,

and in heavy drinkers, suggesting that both groups may be more sensitive to the negative effects of abdominal fat accumulation. Men tend to store fat in the form of visceral fat, which has higher pro-inflammatory properties[18], and heavy alcohol consumption may lead to metabolic disturbances and nutritional imbalances that exacerbate the risk of frailty[19]. These findings emphasize the importance of identifying high-risk groups in the context of the individual and targeting interventions.

Recent years have seen a surge in studies on the connection between frailty and metabolic health, body fat distribution, and obesity. Yuan et al. found a U-shaped association between frailty and both BMI and WC, as well as a high correlation between abdominal obesity and frailty through a systematic review and meta-analysis[20]. Our findings, which demonstrated a strong association between CI and the prevalence of frailty, further corroborated this hypothesis. Furthermore, WC has been shown to be a more reliable indicator of older persons' risk of frailty than BMI[21,22]. Our study further demonstrates that WC is more accurate than BMI in both male and female populations. More importantly, CI is more accurate than WC in predicting frailty in older adults. According to He et al., obesity that was metabolically unhealthy considerably sped up the development of frailty, while obesity that was metabolically healthy had less of an impact[23]. Our study also showed that individuals with higher CI are usually accompanied by poorer metabolic health status, increasing the risk of frailty prevalence. In addition, our study shows a threshold effect and nonlinear association between CI and frailty for the first time, indicating that in both male and female populations, the prevalence of frailty is significantly higher when the CI is greater than 1.35. This threshold may correspond to a physiologic transition from compensation to imbalance. After a certain level of CI, abdominal fat may have entered a dysfunctional state characterized by a high release of pro-inflammatory cytokines, adipose tissue hypoxia, and mitochondrial dysfunction[24], leading to a markedly increased systemic inflammatory response. At the same time, muscle mass loss, worsening insulin resistance, hormonal disturbances and elevated levels of oxidative stress are more pronounced[25]. Thus, when the CI exceeds the threshold of 1.35, the above pathologic processes may act synergistically to accelerate the onset of frailty. Although this threshold may be variable in different populations, our findings suggest that CI has potential stratification significance in identifying at-risk individuals.

Abdominal fat accumulation raises the risk of frailty through a number of pathophysiologic mechanisms. One metabolically active tissue that can secrete a number of pro-inflammatory factors, including interleukin-6 and tumor necrosis factor-alpha, is abdominal fat. These factors cause a systemic, chronic, low-grade inflammation that speeds up the loss of muscle mass and strength, which leads to the development of frailty[26]. One of the primary causes of weakness is believed to be this inflammatory condition. People who have a high CI are more likely to have larger reserves of belly fat and are more vulnerable to the harmful consequences of the inflammatory response. In addition to affecting muscle mass, this persistent low-grade inflammation may hasten the deterioration of other systems by causing oxidative stress[27]. The development of insulin resistance is intimately associated with obesity, which in turn directly contributes to metabolic illnesses including diabetes and hyperlipidemia, which in turn hasten the onset of frailty[28]. Because abdominal fat is accurately reflected by CI, we found that CI was a better predictor of frailty than BMI in this study. Additionally, abdominal obesity is linked to a number of hormonal imbalances, such as abnormalities in leptin[29], insulin-like growth factor[30], and sex hormone-binding globulin[31]. Obese people tend to have lower levels of IGF-1 and increased leptin resistance[32], which may worsen the condition of frailty. These hormones have significant impacts on muscle mass and bone strength in addition to being strongly linked to energy metabolism and fat distribution. Also, abdominal obesity is strongly associated with cardiovascular disease risk. By causing harm to the cardiovascular system, higher CI may hasten the onset of frailty[33]. Through the indirect effects of decreased physical activity, changed dietary patterns, and heightened chronic inflammation, excessive obesity is frequently linked to higher levels of psychological issues like anxiety and depression[34], which may hasten the onset of frailty[35]. The ROC analysis in this study found that CI was a better predictor of frailty than BMI and WC in men and relatively weaker in women. The likely reason for this is that men are more likely to accumulate visceral fat[18], and elevated CI tends to directly reflect abnormal accumulation of visceral fat, which in turn leads to a more pronounced systemic inflammatory response and metabolic disturbances, mechanisms that are strongly associated with the development of frailty. In contrast, women more commonly exhibit increased subcutaneous fat, which has lower metabolic activity and inflammatory potential, and CI may not adequately reflect the underlying risk of frailty in women. In addition, estrogen levels in women may be protective against inflammation and fat distribution[36], thus weakening the association between CI and frailty. This result suggests that the moderating role of gender factors on fat distribution patterns and pathophysiologic mechanisms should be considered when assessing the risk of frailty.

Because the study is based on NHANES data, which has a large and nationally representative sample size, its conclusions are more reliable. The reliability of the results was improved by the study's adjustment for a number of possible confounders, such as age, gender, race, and lifestyle characteristics. The results' robustness was further supported by subgroup analyses, which revealed a strong correlation between CI and frailty in all groups. The study also had limitations. As there is no uniform international classification standard for CI. This study uses quartiles for grouping, aiming to achieve internal risk stratification based on the study sample. However, the external comparability of this method is limited. In the future, large-scale cohort studies should be relied upon to establish normative ranges and clinical classification boundaries for CI to enhance its practical value in disease screening and risk prediction. The data came from a cross-sectional survey, so it was not possible to prove a causal relationship between CI and frailty; further longitudinal research is needed to confirm this; even after controlling for a number of variables, there may be potential confounders (e.g., genetic factors, etc.) that were missed; the study population was an older U.S. population, and further validation is needed to determine whether the findings apply to other regions or ethnicities.

Conclusion

This study showed a strong positive correlation between CI and frailty in older Americans, emphasizing the significance of taking metabolic parameters into account when developing prevention and treatment plans for frailty. Future research should examine how well strategies to lower CI and slow the onset of frailty work. These findings demonstrate the potential of CI as a screening and management tool for frailty; however, larger prospective studies are needed for further confirmation.

Data availability

Data is provided within the manuscript or supplementary information files.

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J.X. and M.C. designed the research. J.X. collected, analyzed the data, and drafted the manuscript. JM.C., and XB. L. revised the manuscript. All authors contributed to the article and approved the submitted version.

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Declarations

Competing interests
The authors declare no competing interests.

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