# J-shaped relationship between relative fat mass and osteoarthritis: a US population-based study

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## Abstract

**Introduction:** Osteoarthritis (OA) is a common chronic joint disease that severely affects patients' quality of life and causes a significant socioeconomic burden. The aim of this study was to investigate the association between relative fat mass (RFM) and OA and to assess the diagnostic efficacy of RFM in predicting OA risk.

**Material and methods:** We conducted a cross-sectional analysis using data from the National Health and Nutrition Examination Survey (NHANES) from 2001 to 2020. Thirty-nine thousand six hundred and fifty-eight study participants were included in the study, which used multifactorial logistic regression analyses, stratified analyses, restricted cubic spline curves (RCS), and ROC curves to explore the association between RFM and OA.

**Results:** RFM was significantly and positively associated with OA, which remained statistically significant after correction for confounders (OR = 1.062, 95% CI: 1.056–1.069, $p < 0.0001$). Restricted cubic spline (RCS) analysis showed a J-shaped relationship between RFM and OA ($p = 0.024$ for non-linear test). Stratified analyses further confirmed that the association between RFM and OA was positive in all subgroups, and the strength of this association varied by age and ethnicity ($p < 0.05$ for interaction). ROC curve analyses showed that RFM was significantly more diagnostic of OA than body weight, waist circumference (WC) and body mass index (BMI), with areas under the curve (AUC) of 0.646, 0.550, 0.621 and 0.550, respectively.

**Conclusions:** RFM may be an important risk factor for OA and has a diagnostic efficacy superior to traditional anthropometric indices in predicting OA risk. Future studies should further explore the mechanisms linking RFM and OA and validate its clinical applicability, with a view to providing new insights and methods for the prevention and diagnosis of OA.

**Key words:** relative fat mass, osteoarthritis, J-shaped relationship, National Health and Nutrition Examination Survey.

## Introduction

Osteoarthritis (OA) is a common joint disease characterised by degeneration and wear and tear of articular cartilage and osteophytes on the joint margins and subchondral bone [1]. It is a chronic, progressive disease that usually results in joint pain, stiffness, swelling and limited movement. Osteoarthritis can affect any joint in the body, most com-

monly the knees, hips, finger joints and spinal joints, which also has a greater impact on the quality of daily life of people with OA. The incidence of OA has been increasing over the past few decades as the population ages [2]. However, the exact mechanisms underlying the pathogenesis of OA are unknown, and therefore effective treatments are lacking.

Obesity is a major global health problem whose frequency is steadily increasing every year [3]. Relative fat mass (RFM) is a novel obesity assessment metric validated by dual-energy X-ray absorptiometry (DXA), which more accurately quantifies body fat compared to traditional metrics such as body mass index (BMI) or waist circumference (WC) [4]. RFM is calculated by a linear equation of height and WC, which is a simple and cross-racially validated algorithm [5]. Studies have shown that RFM is associated with a variety of health problems, including diabetes, heart disease, and all-cause mortality, and outperforms traditional obesity metrics in predicting mortality [6]. Obesity is a known risk factor for OA, and higher body fat, particularly abdominal fat, has been linked to inflammation and metabolic problems, all of which may contribute to the development of OA [7]. Epidemiological studies have found that obese people are significantly more likely to develop OA than normal weight people [8]. These health problems share risk factors with OA, which further implies that RFM may be associated with OA risk.

However, there is currently no direct evidence linking RFM to OA. While a direct relationship cannot be confirmed, the correlations between RFM and other health problems make it reasonable to hypothesize that RFM may be associated with OA risk. Therefore, using the NHANES database, this study aimed to evaluate the relationship between RFM and OA risk.

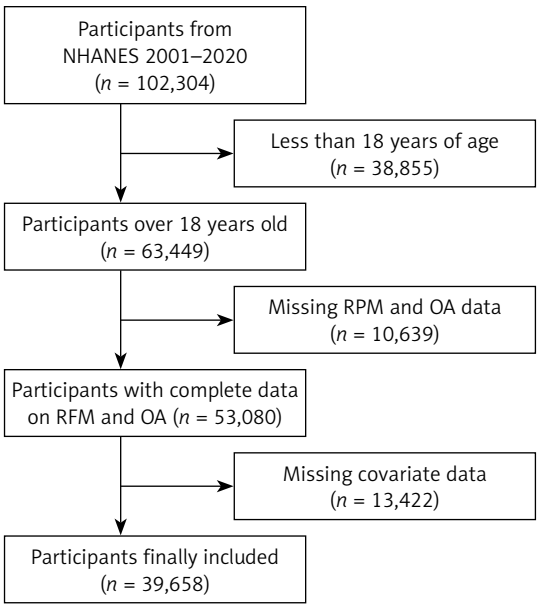


**Figure 1.** Flowchart

## Material and methods

### Study design and participants

NHANES is an ongoing national cross-sectional survey with data available on the website of the Centers for Disease Control and Prevention (CDC) (http://www.cdc.gov/nchs/nhanes.htm). Of the 102,304 participants recruited, we used specific criteria to select subjects. Individuals were excluded if they met the following criteria: (1) age less than 18 years ($n$ = 38,855); (2) missing RFM and OA data ($n$ = 10,639); and (3) missing covariate data ($n$ = 13,422). Thus, the final cohort consisted of 39,658 participants, as shown in Figure 1.

### Relative fat mass

RFM is calculated using the following formula: RFM = 64 – (20 × height/WC) + (12 × sex), sex = 1 for women and 0 for men [9]. Height and WC were measured by Mobile Examination Centre (MEC) professionals. The upper edge of the iliac crest is where WC is measured [10], whereas height is measured using a specialised height measuring MEC device [11]. Both are measured in centimetres (cm).

### Assessment of OA

One study showed 81% agreement between self-report and clinical confirmation of OA [12]. In NHANES, arthritis diagnosis data are part of self-reported personal interview data [13]. Briefly, the researchers asked all participants aged ≥ 20 years one question related to arthritis, specifically: 'Has a doctor or other health professional ever told you that you have arthritis?' Participants who answered yes were included in the study.

### Covariates

Primary covariates included demographic information (age, weight, height, poverty, race, and marital status), health habits (smoking and alcohol use), and health status (diabetes, hypertension, chronic kidney disease). Race was categorised as Mexican American, non-Hispanic Black, non-Hispanic White, or Other; educational attainment was categorised as high school diploma, high school graduation, or college; marital status was categorised as divorced/separated/widowed, married/living with a partner, or unmarried; poverty income ratio (PIR) was categorised as PIR < 1.3, 1.3 < PIR < 3.5, or PIR > 3.5; and smoking intensity was measured by smoking quantity: never smoker (less than 100 cigarettes in a lifetime), ex-smoker (more than 100 cigarettes in a lifetime,

but quit), or current smoker. Alcohol consumption status was measured by the amount of alcohol consumed. Health status was determined by physician diagnosis or self-report and included diseases such as diabetes, hypertension, and chronic kidney disease (CKD). Pooled data for all study variables are accessible on the NHANES website at www.cdc.gov/nchs/nhanes/.

### Statistical analysis

Baseline characteristics of continuous variables were expressed as mean ± standard deviation (SD), while those of categorical variables were expressed as percentages. To compare the differences between different RFM levels, weighted multivariate logistic regression analyses were performed to assess the relationship between RFM and OA in the three different models. The main purpose of weighting is to make the sample better reflect the overall characteristics. To explore the association between RFM and OA in different subgroups, we stratified by age, gender, race, and marriage. In addition, quartiles of RFM were used as categorical variables for subgroup analyses, where OR denotes the coefficient of the highest quartile of RFM level (Q4) compared to the lowest quartile (Q1). In addition, restricted cubic spline (RCS) was used in this study to deal with possible non-linear associations between RFM and OA and to visualise non-linear associations. To assess the value of each obesity metric in OA, subject work characteristics (ROC) curves were plotted and the area under the curve (AUC) was calculated to quantify the results. A two-sided *p*-value of less than 0.05 was considered statistically significant. All analyses in this study were performed with R version 4.2.3 (www.R-project.org).

## Results

### Baseline characteristics

Baseline characteristics of the population grouped by RFM quartiles (Q1–Q4) are shown in Table I, weighted by RFM quartile level. A total of 39,658 study participants were enrolled in this study, with the majority of subjects being female (50.5%) and non-Hispanic White (70.26%). Participants with higher RFM were older, female, and divorced/separated/widowed. The prevalence of OA across RFM quartiles Q1–Q4 was 13.16%, 22.23%, 26.76%, and 39.33%, respectively.

### Association between RFM and OA

Multifactor logistic regression analysis showed that RFM was positively associated with OA in the unadjusted model (OR = 1.065, 95% CI: 1.062–1.069, $p < 0.0001$) (Table II). These positive correlations persisted and were statistically significant after correction for confounders in model 3 (OR = 1.062, 95% CI: 1.056–1.069, $p < 0.0001$). Converting RFM from a continuous variable to a categorical variable (quartiles), we found that RFM remained significantly and positively correlated with the risk of OA, and this relationship persisted after correction for confounders. Specifically, in model 1, the highest quartile of RFM was associated with an increased risk of OA compared to Q1 (OR = 4.276, 95% CI: 3.907–4.679, $p < 0.0001$), and this trend persisted in model 3 (OR = 3.139, 95% CI: 2.707–3.640, $p < 0.0001$). The results of restricted cubic spline (RCS) showed a J-shaped relationship between RFM and OA (non-linear test $p = 0.024$), as detailed in Figure 2.

### Stratified analyses

To determine whether the association between RFM levels and OA prevalence was consistent across populations, stratified analyses were performed to further validate the stability of the association between RFM and OA risk across populations (Table III). The results showed that the association between RFM and OA prevalence was consistently positive in all subgroups. Notably, the strength of this association varied by age and ethnicity ($p < 0.05$ for interaction). For each

**Table I.** Baseline characteristics of the population

| Variable | Total | Q1 (7.76,29.04) | Q2 (29.04,34.61) | Q3 (34.61,42.50) | Q4 (42.50,58.03) | *P*-value |
|---|---|---|---|---|---|---|
| Age [years] | 46.88 ±0.20 | 41.29 ±0.24 | 47.69 ±0.24 | 47.79 ±0.26 | 51.31 ±0.25 | < 0.0001 |
| Height | 169.03 ±0.08 | 176.46 ±0.11 | 172.53 ±0.14 | 165.24 ±0.13 | 160.94 ±0.11 | < 0.0001 |
| Weight | 82.76 ±0.19 | 76.74 ±0.19 | 85.09 ±0.31 | 79.10 ±0.38 | 91.22 ±0.29 | < 0.0001 |
| BMI | 28.88 ±0.06 | 24.54 ±0.04 | 28.23 ±0.08 | 28.46 ±0.10 | 35.06 ±0.10 | < 0.0001 |
| Waist circumference | 98.86 ±0.17 | 89.35 ±0.15 | 99.72 ±0.24 | 97.10 ±0.27 | 110.75 ±0.18 | < 0.0001 |
| Age group (%) | | | | | | < 0.0001 |
| < 60 | 75.73 | 86.42 | 75.01 | 73.85 | 66.48 | |
| ≥ 60 | 24.27 | 13.58 | 24.99 | 26.15 | 33.52 | |

**Table I.** Cont.

| Variable | Total | Q1 (7.76,29.04) | Q2 (29.04,34.61) | Q3 (34.61,42.50) | Q4 (42.50,58.03) | *P*-value |
|---|---|---|---|---|---|---|
| Sex, *n* (%) | | | | | | < 0.0001 |
| Female | 50.50 | 4.02 | 25.88 | 78.03 | 99.76 | |
| Male | 49.50 | 95.98 | 74.12 | 21.97 | 0.24 | |
| Race (%) | | | | | | < 0.0001 |
| Mexican American | 7.89 | 6.99 | 8.48 | 6.97 | 9.32 | |
| Non-Hispanic Black | 10.10 | 11.07 | 7.34 | 8.90 | 13.48 | |
| Non-Hispanic White | 70.26 | 68.95 | 73.08 | 71.82 | 66.79 | |
| Other Hispanic | 5.11 | 4.82 | 5.13 | 5.10 | 5.46 | |
| Other race – including multi-racial | 6.63 | 8.17 | 5.98 | 7.21 | 4.96 | |
| Marital status (%) | | | | | | < 0.0001 |
| Divorced/separated/widowed | 17.92 | 11.03 | 13.74 | 20.31 | 27.76 | |
| Married/living with partner | 64.63 | 62.96 | 70.62 | 65.20 | 59.13 | |
| Never married | 17.45 | 26.01 | 15.63 | 14.49 | 13.11 | |
| Education level (%) | | | | | | < 0.0001 |
| Above high school | 61.57 | 63.04 | 62.05 | 64.60 | 55.90 | |
| Completed high school | 23.86 | 22.94 | 23.90 | 22.13 | 26.84 | |
| Less than high school | 14.57 | 14.02 | 14.05 | 13.28 | 17.26 | |
| Smoking status (%) | | | | | | < 0.0001 |
| Former | 25.08 | 22.41 | 30.52 | 23.46 | 23.85 | |
| Never | 54.14 | 50.64 | 49.51 | 57.77 | 59.21 | |
| Current | 20.78 | 26.95 | 19.98 | 18.78 | 16.94 | |
| Alcohol consumption status (%) | | | | | | < 0.0001 |
| Former | 12.59 | 9.39 | 12.82 | 12.26 | 16.38 | |
| Heavy | 21.87 | 26.94 | 23.43 | 20.03 | 16.43 | |
| Mild | 37.33 | 43.52 | 39.52 | 34.55 | 30.99 | |
| Moderate | 17.89 | 13.43 | 16.88 | 21.65 | 19.78 | |
| Never | 10.32 | 6.72 | 7.35 | 11.51 | 16.41 | |
| PIR (%) | | | | | | < 0.0001 |
| < 1.3 | 19.60 | 19.46 | 16.14 | 18.03 | 25.47 | |
| 1.3–3.5 | 35.42 | 33.43 | 34.05 | 35.70 | 38.91 | |
| ≥ 3.5 | 44.98 | 47.10 | 49.81 | 46.27 | 35.62 | |
| Diabetes (%) | | | | | | < 0.0001 |
| No | 87.17 | 94.62 | 86.96 | 88.14 | 77.78 | |
| Yes | 12.83 | 5.38 | 13.04 | 11.86 | 22.22 | |
| Hypertension (%) | | | | | | < 0.0001 |
| No | 63.15 | 75.89 | 62.08 | 63.83 | 49.03 | |
| Yes | 36.85 | 24.11 | 37.92 | 36.17 | 50.97 | |
| CKD (%) | | | | | | < 0.0001 |
| No | 86.53 | 93.03 | 86.40 | 85.05 | 80.95 | |
| Yes | 13.47 | 6.97 | 13.60 | 14.95 | 19.05 | |
| OA (%) | | | | | | < 0.0001 |
| No | 75.07 | 86.84 | 77.77 | 73.24 | 60.67 | |
| Yes | 24.93 | 13.16 | 22.23 | 26.76 | 39.33 | |

*Continuous variables are presented as mean + standard deviation (SD). Categorical variables are presented as percentages. RFM – relative fat mass, BMI – body mass index, PIR – poverty income ratio, CKD – chronic kidney disease, OA – osteoarthritis.*

**Table II.** Relationship between RFM and OA

| Exposure | Model 1 | | Model 2 | | Model 3 | |
|---|---|---|---|---|---|---|
| | OR (95% CI) | *P*-value | OR (95% CI) | *P*-value | OR (95% CI) | *P*-value |
| RFM | 1.065 (1.062,1.069) | < 0.0001 | 1.071 (1.064,1.077) | < 0.0001 | 1.062 (1.056,1.069) | < 0.0001 |
| RFM (quartile) | | | | | | |
| Q1 | ref | | ref | | ref | |
| Q2 | 1.886 (1.712,2.076) | < 0.0001 | 1.439 (1.291,1.604) | < 0.0001 | 1.362 (1.217,1.524) | < 0.0001 |
| Q3 | 2.410 (2.173,2.672) | < 0.0001 | 2.200 (1.921,2.519) | < 0.0001 | 1.972 (1.718,2.264) | < 0.0001 |
| Q4 | 4.276 (3.907,4.679) | < 0.0001 | 3.793 (3.291,4.371) | < 0.0001 | 3.139 (2.707,3.640) | < 0.0001 |
| *P* for trend | | < 0.0001 | | < 0.0001 | | < 0.0001 |

*Model 1 was unadjusted; Model 2 was adjusted for age, gender, and race/ethnicity; and Model 3 was adjusted for Model 2 plus marriage, PIR, educational attainment, and smoking.*

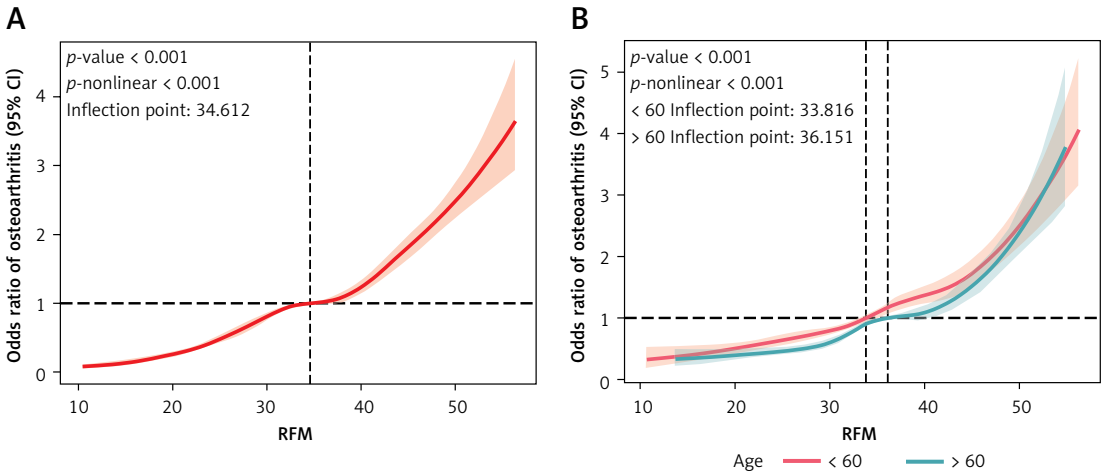


**Figure 2.** J-shaped relationship between RFM and OA as analysed by the restricted cubic spline curve (RCS)

unit increase in RFM, the risk of OA increased by 6.4% in those aged 60 years or older (OR = 1.064 (1.051–1.077)), whereas the risk of OA increased by 6.2% in those aged less than 60 years (OR = 1.062 (1.053–1.071)). Interestingly, race also influenced the relationship between RFM and OA, with a 9% increase in the risk of OA in other races (including mixed race) for each unit of elevated RFM (OR = 1.090 (1.058–1.123)) and a 5.7% increase in Mexican Americans (OR = 1.057 (1.036–1.079)). We did not observe additional statistically significant interaction effects, implying that the risk relationship between RFM and OA was not influenced by factors other than age and race.

### ROC analysis

In this study, ROC curves were used to assess the ability of four anthropometric measures to discriminate patients with OA. ROC curve analysis revealed that RFM was significantly more diagnostic of OA than body weight, WC, and BMI. The AUC for RFM, body weight, WC, and BMI were 0.646, 0.550, 0.621, and 0.596, respectively (Figure 3). These findings suggest that RFM may provide greater diagnostic efficacy than traditional anthropometric measures in predicting OA risk.

## Discussion

To our knowledge, this is the first cross-sectional study to investigate the correlation between RFM and OA. In this study, based on a US population, we found a positive association between RFM and OA in a J-shaped pattern, with higher levels of RFM associated with a higher risk of OA. Of note, for every unit increase in RFM, there was a 6.4% increase in the risk of OA in those older than 60 years and a 6.2% increase in the risk of OA in those younger than 60 years, implying that more attention should be paid to RFM levels in those aged over 60 years. Race also influences the relationship between RFM and OA, and ROC curve analyses suggest that RFM may provide greater diagnostic efficacy than traditional anthropometric measures in predicting OA risk.

Osteoarthritis is a major global burden, affecting more than 500 million people worldwide. It is characterised by degeneration and loss of articular cartilage, synovial inflammation and subchondral bone sclerosis, leading to pain and dysfunction. After age, obesity is the main modifiable risk factor for OA and has recently been identified as a chronic disease [14]. Moreover, one Mendelian randomisation study demonstrated that cheese

**Table III.** Subgroup analyses stratified by sex, age, race, marriage, education, smoking, and alcohol use

| Parameter | OA | |
|---|---|---|
| | OR (95% CI) | *P*-value |
| Sex | | |
| Male | 1.070 (1.058–1.082) | < 0.0001 |
| Female | 1.058 (1.049–1.066) | < 0.0001 |
| *P* for interaction | 0.603 | |
| Age | | |
| < 60 | 1.062 (1.053–1.071) | < 0.0001 |
| ≥ 60 | 1.064 (1.051–1.077) | < 0.0001 |
| *P* for interaction | 0.043 | |
| Race/ethnicity | | |
| Non-Hispanic White | 1.059 (1.051–1.067) | < 0.0001 |
| Mexican American | 1.057 (1.036–1.079) | < 0.0001 |
| Other race – including multi-racial | 1.090 (1.058–1.123) | < 0.0001 |
| Non-Hispanic Black | 1.070 (1.056–1.085) | < 0.0001 |
| Other Hispanic | 1.074 (1.045–1.104) | < 0.0001 |
| *P* for interaction | 0.026 | |
| Marital Status | | |
| Divorced/separated/widowed | 1.060 (1.046–1.075) | < 0.0001 |
| Married/living with partner | 1.064 (1.056–1.073) | < 0.0001 |
| Never married | 1.049 (1.030–1.068) | < 0.0001 |
| *P* for interaction | 0.387 | |
| Educational achievement | | |
| College | 1.067 (1.058–1.077) | < 0.0001 |
| High school diploma | 1.057 (1.042–1.073) | < 0.0001 |
| Completed high school | 1.051 (1.038–1.065) | < 0.0001 |
| *P* for interaction | 0.66 | |
| Smoking status | | |
| Current smoker | 1.060 (1.046–1.075) | < 0.0001 |
| Former smoker | 1.064 (1.056–1.073) | < 0.0001 |
| Never smoked | 1.049 (1.030–1.068) | < 0.0001 |
| *P* for interaction | 0.387 | |
| Alcohol consumption status | | |
| Mild | 1.071 (1.058–1.084) | < 0.0001 |
| Moderate | 1.057 (1.039–1.075) | < 0.0001 |
| Former | 1.058 (1.041–1.075) | < 0.0001 |
| Heavy | 1.045 (1.028–1.063) | < 0.0001 |
| Never | 1.066 (1.042–1.091) | < 0.0001 |
| *P* for interaction | 0.139 | |

*Adjusted for all covariates except the stratification factor itself.*

consumption exerts a protective effect against OA [15], whilst another Mendelian randomisation study identified a causal relationship between total body water mass and OA [16]. These studies shed light from different angles on the impact of lifestyle and body composition on OA, further underscoring the importance of obesity management in OA prevention. The close association between obesity and OA allows them to influence each other and exacerbate each other's pathological processes, worsening the prognosis of patients [17]. Weight management is an important aspect in the management of OA. In patients with OA of the hip, weight loss is recommended as a management approach and is essential for the management of OA [18]. BMI and WC are common

indicators of obesity, representing obesity and abdominal obesity, respectively, and both are independently associated with pain, disability, and imaging severity in knee OA [19, 20]. Higher BMI and WC were also found to be associated with a higher prevalence and risk of OA in a cross-sectional survey based on Koreans, with individuals with generalised obesity and abdominal obesity having a 1.73-fold increased odds of developing OA compared with individuals without any general obesity or abdominal obesity (OR = 1.73; 95% CI: 1.53–1.95) [21]. However, BMI is unable to differentiate between lean body mass and fat mass, or visceral fat and subcutaneous fat [22], and WC does not take into account factors such as the body's bone structure and muscle mass. RFM, a newer anthropometric measure that more accurately estimates the proportion of total body fat, is associated with a lower rate of misclassification of obesity compared with BMI [9]. In our study, as far as the assessment of OA risk is concerned, this indicator, RFM, demonstrated superior diagnostic efficacy compared to traditional anthropometric indicators such as BMI and WC, and its correlation with OA risk was more prominently demonstrated, a result consistent with the properties of RFM as a more accurate indicator of fat distribution. However, despite the superior diagnostic efficacy of RFM over traditional indicators, its AUC value was still lower than 0.7, suggesting that RFM alone may not be sufficient as an independent diagnostic tool for OA. Future studies should consider combining RFM with other biomarkers or imaging indicators to improve the early diagnostic accuracy of OA.

RFM provides a more nuanced understanding of the distribution of visceral fat and body fat in lean body mass patients, which tends to accumulate in the lumbar and abdominal regions with age, contributing to the development of a centrally obese body type. This centrally obese state usually has an impact on the pathogenesis of OA by virtue of mechanisms such as inflammatory response-mediated, oxidative stress injury, increased joint load bearing, and fluctuating hormone levels in the body, which in turn increase the risk of developing OA [23]. In addition, metabolic disorders may also play a role: high visceral fat levels are thought to lead to an overall reduction in androgen production [24]; RFM was found to be associated with testosterone deficiency in adult males in a population-based study [25]; and reduced levels of androgens were reported to weaken the protective effects of articular cartilage, decrease the attachment of periarticular muscle forces, and increase local joint inflammation [26]. These findings suggest that RFM is not only an indicator of fat distribution, but may also be directly involved in the pathogenesis of OA by modulating inflammation and metabolism-related molecular mechanisms.

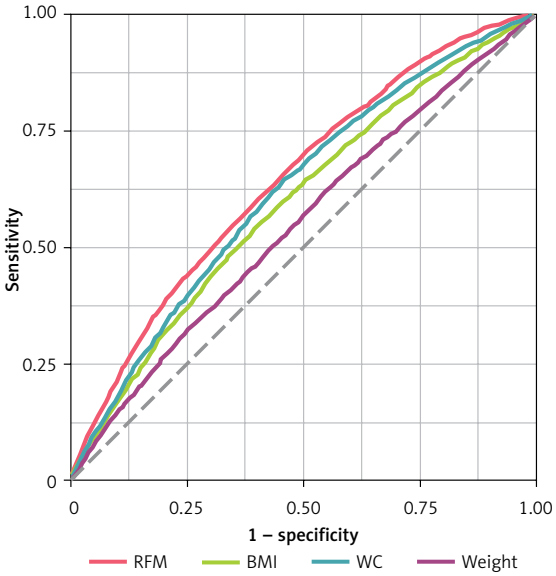


**Figure 3.** ROC curves and AUC values of anthropometric measures (RFM, BMI, WC, Weight) in diagnosing OA

Stratified analyses further revealed the heterogeneity of the association between RFM and OA, especially among different ages. Sex hormone levels decreased significantly in older adults, resulting in more visceral fat deposition and a significant decrease in subcutaneous fat [27, 28]. This may explain our finding that the risk of OA was significantly higher with increasing RFM in adults aged over 60 years compared to those younger than 60 years. In addition, racial differences significantly affected the strength of the association between RFM and OA, with the greatest increase in OA risk in other races (including mixed race) and a relatively small increase in risk in Mexican Americans. These differences may reflect the complex interaction effect of genetic, lifestyle, and environmental factors on fat distribution and OA risk. Although we did not observe other significant interaction effects, this finding suggests that future studies should further explore the specific mechanisms of age and ethnicity in the relationship between RFM and OA in order to develop personalised prevention and treatment strategies for different populations.

Notably, RCS analysis showed that the relationship between RFM and OA exhibited a J-shaped curve, suggesting that there may be a nonlinear association between the two. This nonlinear relationship may reflect the complex effects of fat distribution on joint loading and inflammatory responses. For example, low RFM levels may not be sufficient to trigger significant joint damage, whereas high RFM levels may significantly increase the risk of OA by increasing mechanical

loading and the release of pro-inflammatory adipokines. In addition, the strength of the association with OA was further increased when RFM was used as a categorical variable, especially in the highest quartile group, where the risk of OA increased by 214%. This result highlights the potential application of RFM in OA risk assessment, especially for early screening and intervention in high-risk populations.

Apart from obesity, RFM is associated with multiple diseases. For instance, compared to the TyG index alone, TyG-RFM demonstrates a more pronounced association with cardiovascular events, while RFM itself shows a positive correlation with stroke [29, 30]. This underscores its broad utility in public health screening programmes. Consequently, measuring RFM offers additional advantages for comprehensive health assessments, aiding in the early identification of populations at high risk for multiple chronic diseases and facilitating the development of integrated preventive healthcare systems.

The clinical significance of RFM lies in its ability to provide a more accurate estimation of body fat distribution, which is closely linked to metabolic and inflammatory pathways involved in OA pathogenesis. To integrate RFM into clinical guidelines and practice, we propose its inclusion as a routine anthropometric measure in primary care settings for assessing obesity-related joint disease risk. RFM could be particularly useful in identifying individuals with normal BMI but high body fat ("normal-weight obesity"), who might otherwise be overlooked. Furthermore, RFM may aid in tailoring weight management strategies for both underweight and obese patients by offering a more nuanced understanding of body composition, thereby supporting personalized interventions to mitigate OA risk.

This study has several strengths. Firstly, we used a large sample and weighted all the data, which helped to ensure the generalisability of the findings. This comprehensive data weighting process allowed us to apply the results to a wider range of areas. Second, we made careful adjustments for multiple covariates. Such adjustments are essential to minimise the impact of confounders on the results, thereby greatly improving the stability and reliability of the results. The present study has some limitations that need to be improved in future studies. First, this study relied primarily on cross-sectional data and was unable to determine the causal relationship between RFM and OA. Second, although we used multifactorial logistic regression analyses to control for confounding factors, there may still be unmeasured confounding variables that influence the results. Finally, this study did not incorporate wet-lab or clinical validation analyses, which may affect the biological interpretation of the results and the value of clinical applications. Future studies should consider a longitudinal design to increase sample diversity and incorporate experimental validation to further validate the association between RFM and OA and its underlying mechanisms.

In conclusion, this study revealed a significant positive association between RFM and OA through multifactorial and stratified analyses and found that RFM was superior to traditional anthropometric measures in predicting the risk of OA. Age and race were interactive factors between RFM and OA. These findings provide new insights for early diagnosis and personalised prevention of OA.

## Data availability

Publicly available datasets were analysed in this study. These data can be found at: http://www.cdc.gov/nchs/nhanes/.

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## Ethical approval

In accordance with the Declaration of Helsinki, the National Center for Health Statistics (NCHS) conducted a thorough review and approved all NHANES procedures. Written informed consent was also obtained from each participant involved in the annual survey. It is important to emphasise that our ongoing study does not contain any material from which individuals can be identified. Furthermore, given the nature of this study, no further ethical review was required. All data used can be accessed and retrieved directly from the official NHANES website.

## Conflict of interest

The authors declare no conflict of interest.

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