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Association between relative fat mass and periodontitis: results from NHANES 2009–2014

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Relative fat mass (RFM) is a novel indicator for measuring body fat. This cross-section study aims to explore the association between RFM and periodontitis and to investigate possible effect modifiers in U.S. adults based on the National Health and Nutrition Examination Survey 2009–2014. The category of periodontitis was defined by the CDC/AAP. Mean clinical attachment loss and mean pocket probing depth (PPD) were calculated. The RFM formula is: $64 - (20 \times \text{height}/\text{WC}) + (12 \times \text{sex})$, with sex coded as 1 for female and 0 for male. Natural cubic spline and weighted multivariable regression analyses were conducted to investigate the relationship between RFM and periodontal status. Subgroup and interaction analyses were also employed to assess the moderating roles of age, gender, and race. A total of 10,307 participants were included in our study. Compared to the lowest quartiles, individuals in the highest quartiles of RFM levels were more likely to have moderate/severe periodontitis ($\text{OR}_{\text{Q4vs1}} = 1.64$, 95% CI 1.30–2.06) and had a higher mean PPD ($\beta_{\text{Q4vs1}} = 0.15$, 95% CI 0.09–0.22). This association was particularly stronger in populations under the age of 60, with significant interactions. Taken together, RFM is positively associated with periodontitis, particularly in those under 60 years old.

Keywords Periodontitis, Relative fat mass, NHANES, Cross-sectional study

Periodontitis is a widespread health concern, with over 50% of adults globally afflicted by the condition. It is characterized by the breakdown of the soft and hard tissues surrounding the teeth, primarily caused by bacteria present in dental plaque. Additionally, the host immune response plays a crucial role in the onset and progression of periodontitis^{1,2}. Notably, obesity can affect the host-microbial homeostasis, increasing the risk of developing periodontitis^{3,4}.

Obesity is a metabolic condition resulting from an energy imbalance (consumption < intake), leading to an increase in adipose tissue deposits. While the most common method uses body mass index (BMI) as an indicator of obesity, BMI does not account for frame size or differentiate between fat mass, bone mass, and muscle mass^{5,6}. To provide more accurate anthropometric measures of adiposity, various indices such as body shape index, body shape index, and weight-adjusted waist index have been developed. Recently, a simple new algorithm called relative fat mass (RFM) has been introduced to estimate whole-body fat percentage in adults⁷. RFM has been shown to be the strongest predictor of heart failure risk in the general population⁸. Additionally, higher RFM is associated with hypertension⁹, depression¹⁰, and type 2 diabetes¹¹.

RFM does not have the disadvantages of previously used measures of overweight and obesity. Thus, in this cross-sectional study, we aimed to explore the association between RFM and periodontitis and to investigate possible effect modifiers in U.S. adults based on the National Health and Nutrition Examination Survey (NHANES) 2009–2014.

Methods

Study population

The data utilized in this cross-sectional study were obtained from the NHANES 2009–2014 survey, conducted by the National Center for Health Statistics (NCHS) to ensure representation of the national population. NHANES is a stratified, multistage, clustered probability sampling study that gathered data through interviews as well as

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physical and laboratory examinations^{12,13}. For this study, we excluded individuals who did not undergo a complete full-mouth periodontal examination (FMPE), those for whom data on assessing RFM was unavailable, and individuals under the age of 30. We reported this study following the STROBE criteria for observational studies in epidemiology¹⁴.

Exposure variable

Height and waist circumference (WC) were assessed by a health professional at the Mobile Examination Center (MEC) to determine the Ratio of Fat Mass (RFM), considering the participant's sex. Participants stood barefoot against a special height measuring device at the MEC, ensuring their heads were level with their backs to the board. WC was measured at the line above the iliac crest in the mid-axillary line at the end of normal breathing, with measurements precise to within 0.1 cm¹⁰. The units for height and WC were both in centimeters. The RFM formula is: $64 - (20 \times \text{height}/\text{WC}) + (12 \times \text{sex})$, with sex coded as 1 for female and 0 for male⁷.

Outcome variable

The study's outcome was defined as moderate to severe periodontitis. The periodontal assessment involved measuring clinical attachment loss (CAL) and probing pocket depth (PPD) at six predetermined sites on each tooth, following the FMPE protocol and excluding the third molars. CAL refers to the distance between the cemento-enamel junction and the base of the sulcus, whereas PPD is the measurement from the free gingival margin to the base of the sulcus. The classification of periodontitis was based on the definitions provided by CDC/AAP¹⁵. No/mild periodontitis was classified as the absence of any indication of moderate/severe periodontitis; moderate periodontitis was defined as having ≥ 2 interproximal sites with a PPD of ≥ 5 mm that were not on the same tooth, or ≥ 2 interproximal sites with a AL of ≥ 4 mm that were not on the same tooth; severe periodontitis was characterized by having ≥ 2 interproximal sites with a AL of ≥ 6 mm that were not on the same tooth, along with at least one interproximal site with a PPD of ≥ 5 mm. Furthermore, we calculated the average values for CAL and PPD to provide a comprehensive understanding of periodontal health.

Covariates

Covariates available in the NHANES database were collected based on previous studies^{16,17}, including age (≤ 60 or > 60 years), sex (male or female), race (non-Hispanic White, non-Hispanic Black, Mexican American or others), marital status (married/living as married, never married or separated/divorced/widowed), smoking status (non-smokers, former-smokers or smokers), recreational activity (vigorous activity, moderate activity or other), work activity (vigorous activity, moderate activity or other), frequency of weekly use of floss/device, diabetes mellitus and hypertension. The data on moderate/vigorous recreational activity and moderate/vigorous work activity were collected based on questionnaire. The diagnosis of diabetes mellitus was established using criteria such as self-reported physician diagnosis, a fasting blood glucose level ≥ 7.0 mmol/L, a glycosylated haemoglobin level (HbA1c) $\geq 6.5\%$, or current use of hypoglycaemic drugs. Similarly, the diagnosis of hypertension was determined based on self-reported physician diagnosis, a diastolic blood pressure measurement of ≥ 80 mmHg, a systolic blood pressure reading of ≥ 130 mmHg, or current use of antihypertensive medications.

Statistical analysis

Weights were determined in our study following the guidelines outlined in the NHANES analysis guide. The calculation of the new 6-year weights was derived from 1/3 of the 2-year MEC weights. Continuous variables were presented using mean and standard error (SE), while categorical variables were described using proportions. To compare baseline characteristics across different RFM levels, analysis of variance (ANOVA) was conducted for continuous variables and the chi-square test for categorical variables.

To avoid arbitrary categorization, restricted cubic splines with four knots was utilized to examine the potential nonlinear relationship of RFM and periodontitis. Two weighted multivariable models were applied to investigate the association between RFM and periodontal health, taking into account possible confounding factors. Model I was adjusted for age, sex, and race, while model II included additional adjustments for marital status, smoking status, recreational activity, work activity, frequency of weekly use of floss/device, diabetes, and hypertension. The weighted odds ratio (OR) and 95% confidence interval (CI) were obtained based on weighted logistic regression analysis, while the weighted β and 95% CI were obtained based on weighted linear regression analysis. Furthermore, stratified analyses and interaction analyses were conducted to assess whether the association between RFM and periodontitis differed by age, sex, and race. In the racial subgroup analysis, we divided the participants into two groups: Non-Hispanic White and Others (Non-Hispanic Black, Mexican American, or others). Additionally, we observed a J-shaped association between the systemic immune-inflammation index (SII) and periodontitis in our previous study, with an inflection point at $\log_2(\text{SII})$ of 8.66¹⁸. Considering the role of obesity-induced low-grade inflammation, we further examined the differences in RFM among different SII and age groups.

We also conducted a sensitivity analysis based on another periodontal classification proposed by the 2017 World Workshop on Periodontal and Peri-Implant Diseases and Conditions¹⁹. The severity of periodontitis was classified into four stages based on the maximum AL: 1–2 mm was classified as Stage I, 3–4 mm as Stage II, and equal to or greater than 5 mm as Stage III/IV. Additionally, management complexity was also taken into account. Patients diagnosed with Stage II periodontitis were reclassified as Stage III if their maximum PPD measurement was ≥ 6 mm. Furthermore, patients diagnosed with Stage III periodontitis were reclassified as Stage IV if they have less than 20 teeth remaining. Stage III/IV periodontitis were set as the outcome; others were set as the reference. A complete case analysis approach was employed in our study owing to the negligible amount of missing data present. All statistical analyses were carried out using R software (version 4.1.2). A significance level of 0.05 was used to determine statistical significance.

Ethics approval and consent to participate

NHANES protocols were approved by the Research Ethics Review Board of the National Center for Health Statistics, U.S. Centers for Disease Control and Prevention (NCHS IRB/ERB Protocol Number: 2009–2010, Protocol #2005–06; 2011–2014, Protocol #2011–17), and data collection was carried out in accordance with the aforementioned protocol. Written informed consent was obtained from all participants.

Results

Baseline characteristics of study samples

As shown in Fig. 1, a total of 10,307 individuals were included in this study, representing an estimated population of approximately 139.5 million non-institutionalized U.S. residents. Table 1 presents the baseline characteristics of the individuals in the study. The average age of participants was 50.68 years, with 50.85% being female. Significant differences were noted in various factors among the different RFM levels, including average age, sex, race, marital status, smoking habit, work activity, recreational activity, frequency of weekly use of floss/device, prevalence of diabetes, hypertension, periodontitis, mean CAL, and mean PPD. The prevalence of moderate/severe periodontitis across the RFM levels was reported as follows: 39.78%, 40.91%, 33.67%, and 35.52%, respectively.

Association between RFM and periodontitis

As depicted in Fig. 2, RFM exhibits a non-linear positive relationship with moderate/severe periodontitis ($P_{\text{non-linearity}} = 0.02$). The risk of periodontitis showed a slight declining trend before RFM reached around 30, and then increased rapidly thereafter until RFM was around 43. Consequently, RFM was categorized into quartiles for further analyses. Initially, an unadjusted model indicated a negative association between RFM and moderate/severe periodontitis ($OR_{Q3vs1} = 0.77$, 95% CI 0.65–0.90; $OR_{Q4vs1} = 0.83$, 95% CI 0.72–0.97). However, in the fully adjusted model, a positive association between RFM and periodontitis was observed ($OR_{Q3vs1} = 1.50$, 95% CI 1.24–1.83; $OR_{Q4vs1} = 1.64$, 95% CI 1.30–2.06) (Table 2). Similarity, RFM demonstrated a positive association with mean PPD ($\beta_{Q3vs1} = 0.11$, 95% CI 0.05–0.17; $\beta_{Q4vs1} = 0.15$, 95% CI 0.09–0.22). There was a positive association between RFM and mean CAL after adjusting for age, sex, and race ($\beta_{Q3vs1} = 0.14$, 95% CI 0.02–0.27; $\beta_{Q4vs1} = 0.22$,

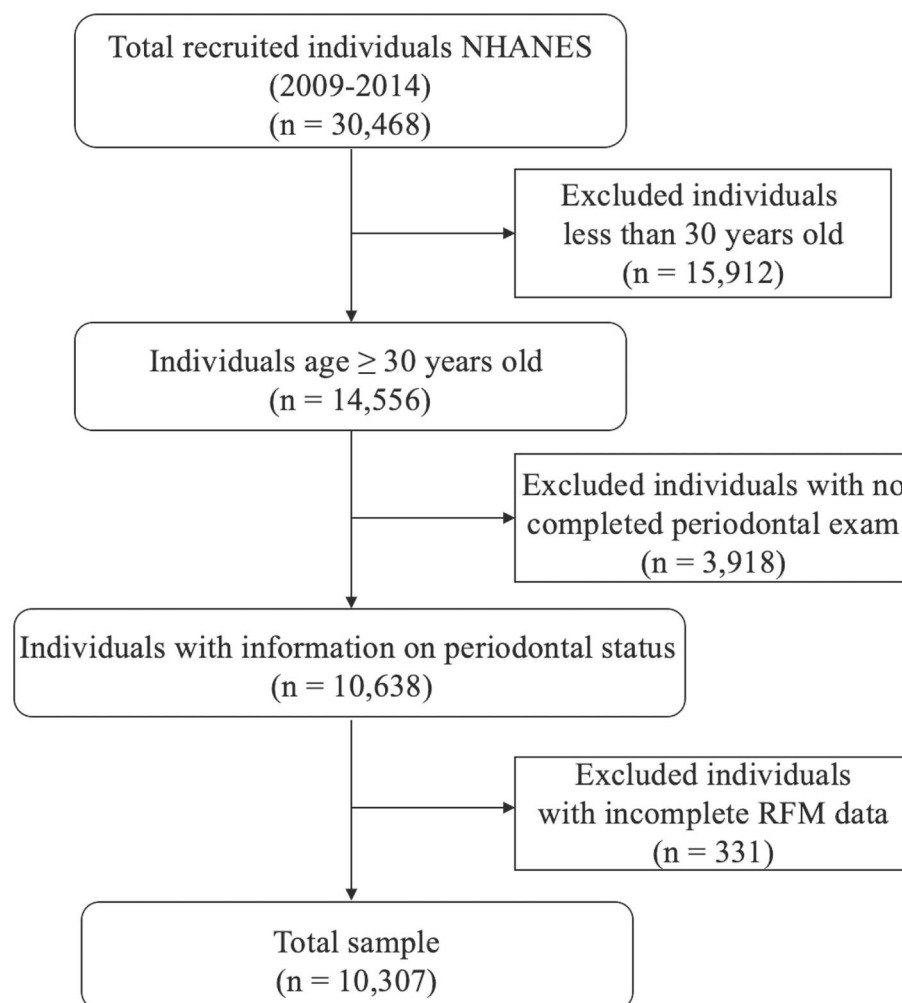


Figure 1. Participant flow chart, 2009–2014 NHANES.

Characteristics	RFM					P value
	Overall (n = 10, 307)	Q1 (9.1–29.3) (n = 2578)	Q2 (29.3–35.2) (n = 2575)	Q3 (35.2–42.9) (n = 2577)	Q4 (42.9–58.4) (n = 2577)	
Age (years), mean (SE)	50.68 (0.24)	47.74 (0.36)	51.40 (0.32)	51.16 (0.34)	52.56 (0.34)	< 0.0001
Age group (%)						< 0.0001
≤ 60	75.92	83.46	74.88	74.44	70.51	
> 60	24.08	16.54	25.12	25.56	29.49	
Sex (%)						< 0.0001
Female	50.85	2.52	23.35	81.97	99.93	
Male	49.15	97.48	76.65	18.03	0.07	
Race (%)						< 0.0001
Non-Hispanic White	68.61	67.5	73.27	69.87	63.03	
Mexican American	8.12	6.49	8.78	6.85	10.6	
Non-Hispanic Black	10.49	10.78	7.69	9.33	14.72	
Others	12.78	15.24	10.25	13.94	11.65	
Marital status (%) ^a						< 0.0001
Never married	10.15	12.32	9.38	8.95	10.02	
Married/living as married	69.81	73.54	75.81	68.31	60.67	
Separated/divorced/widowed	20	14.14	14.81	22.74	29.31	
Smoking habit (%) ^a						< 0.0001
Non smoker	56.33	52.22	52.65	59.03	61.98	
Former smoker	26.24	25.26	30.46	25.85	22.94	
Current smoker	17.42	22.52	16.88	15.12	15.07	
Work activity (%) ^a						< 0.0001
Moderate	22.06	19.2	22.99	23.45	22.56	
Vigorous	4.53	6.82	6.46	2.75	1.85	
Other	73.39	73.98	70.55	73.79	75.59	
Recreational activity (%)						< 0.0001
Moderate	31.33	27.43	31.28	35.07	31.39	
Vigorous	6.92	12.16	7.59	4.95	2.62	
Other	61.75	60.40	61.14	59.98	65.98	
Frequency of weekly use of floss/device (%) ^a						< 0.0001
≤ 2	45.10	52.16	48.60	39.38	40.80	
3–5	20.19	19.00	19.23	21.52	21.55	
≥ 6	34.20	28.83	32.17	39.09	37.64	
Diabetes mellitus (%) ^a						< 0.0001
No	85.06	92.93	85.09	87.04	76.43	
Yes	14.26	7.07	14.91	12.96	23.57	
Hypertension (%) ^a						< 0.0001
No	60.34	70.76	58.32	63.78	47.2	
Yes	39.66	29.24	41.68	36.22	52.8	
Mean CAL (mm), mean (SE)	1.64 (0.03)	1.76 (0.04)	1.74 (0.03)	1.51 (0.04)	1.54 (0.03)	< 0.0001
RFM, mean (SE)	35.59 (0.13)	25.50 (0.08)	32.09 (0.05)	39.10 (0.05)	46.72 (0.08)	< 0.0001
Mean PPD (mm), mean (SE)	1.43 (0.02)	1.51 (0.02)	1.49 (0.02)	1.34 (0.02)	1.38 (0.02)	< 0.0001
Periodontitis (%)						< 0.001
None/mild	62.49	60.22	59.09	66.33	64.48	
Moderate/severe	37.51	39.78	40.91	33.67	35.52	
Periodontitis (%)						< 0.0001
Non/Stage I/II	62.85	59.16	59.03	67.18	66.35	
Stage III/IV	37.15	40.84	40.97	32.82	33.65	

Table 1. Weighted characteristics of the participants (N = 10,307). CAL Clinical attachment loss, PPD Probing pocket depth, SE Standard error. ^aMissing values for total study: marital status (n = 7, 0.068%), smoking habit (n = 3, 0.029%), work activity (n = 2, 0.02%), frequency of weekly use of floss/device (n = 85, 0.82%), diabetes mellitus (n = 63, 0.61%), and hypertension (n = 1, 0.01%).

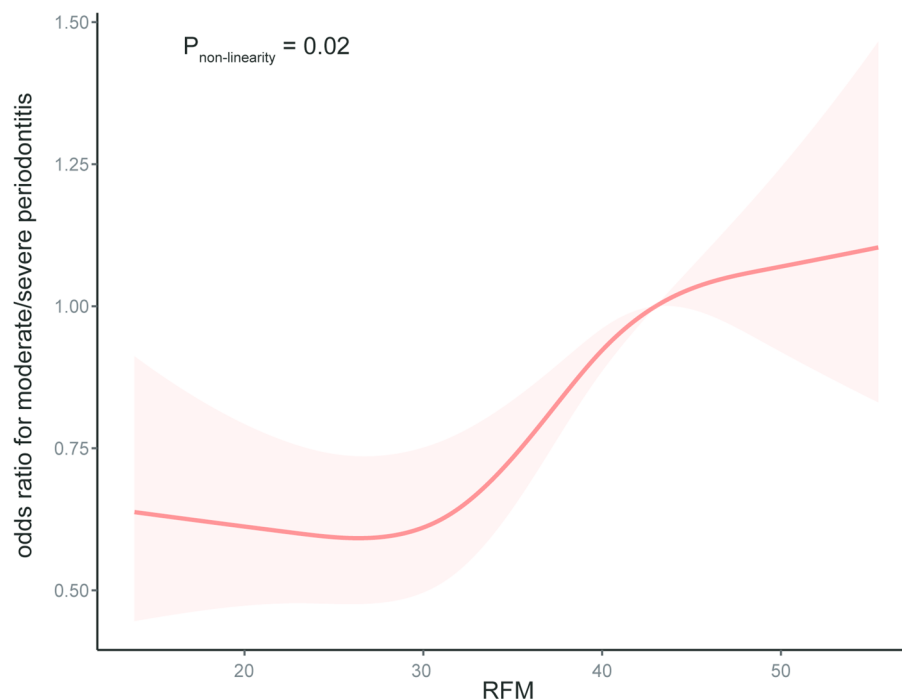


Figure 2. The relationship between RFM and the risk of moderate/severe periodontitis. Adjusted for age, sex, race, marital status, smoking status, recreational activity, work activity, frequency of weekly use of floss/device, diabetes mellitus, and hypertension.

	Crude model	Model I	Model II
	OR (95% CI)	OR (95% CI)	OR (95% CI)
<i>RFM</i>			
Q1 (19.1–29.3)	Ref	Ref	Ref
Q2 (29.3–35.2)	1.05 (0.89, 1.23)	1.21 (1.01, 1.46)	1.16 (0.97, 1.39)
Q3 (35.2–42.9)	0.77 (0.65, 0.90)	1.69 (1.36, 2.10)	1.50 (1.24, 1.83)
Q4 (42.9–58.4)	0.83 (0.72, 0.97)	2.04 (1.62, 2.57)	1.64 (1.30, 2.06)
<i>P</i> for trend	<0.001	<0.0001	<0.001

Table 2. Association between RFM and periodontitis. Model I: Adjusted for age, sex, and race. Model II: Model I additionally adjusted for marital status, smoking status, recreational activity, work activity, frequency of weekly use of floss/device, diabetes mellitus, and hypertension.

95% CI 0.10–0.33). However, no significant association of RFM with mean CAL was found in the fully adjusted model (Table 3).

Subgroup analyses

Age significantly modified the relationship between RFM and periodontitis, revealing distinctive associations across different age groups. Specifically, individuals younger than 60 years old, RFM showed a significant relationship with periodontitis ($OR_{Q3vs1} = 1.67$, 95% CI 1.27–2.19; $OR_{Q4vs1} = 2.21$, 95% CI 1.64–2.96). In contrast, a trend towards an inverse relationship between RFM and periodontitis was observed among older adults ($OR_{Q4vs1} = 0.68$, 95% CI 0.41–1.15) (Table 4 and Fig. S1). In addition, RFM showed a significant association with periodontitis in males ($OR_{Q3vs1} = 1.54$, 95% CI 1.13–2.09), as well as in Whites ($OR_{Q4vs1} = 1.87$, 95% CI 1.34–2.61) and individuals of other races ($OR_{Q4vs1} = 1.54$, 95% CI 1.13–2.11). Considering the role of obesity-induced low-grade inflammation, we further explored the difference in RFM between SII and age groups. The results revealed that individuals under 60 years old with a more active immune response exhibited higher RFM levels. Conversely, in older adults, there was no apparent association between host immune response and RFM (Fig. S2).

Sensitivity analyses

A sensitivity analysis was employed to assess the relationship between RFM and Stage III/IV periodontitis. The results also revealed a similar trend concerning this relationship (Fig. S3 and Table S1). The highest quartiles of RFM decreased the risk of Stage III/IV periodontitis compared to quartiles 1 in the crude model ($OR_{Q4vs1} = 0.73$,

	Crude model	Model I	Model II
	β (95% CI)	β (95% CI)	β (95% CI)
<i>Mean CAL</i>			
Q1 (19.1–29.3)	Ref	Ref	Ref
Q2 (29.3–35.2)	–0.01 (–0.09, 0.06)	0.07 (–0.01, 0.16)	0.05 (–0.03, 0.13)
Q3 (35.2–42.9)	–0.25 (–0.33, –0.17)	0.14 (0.02, 0.27)	0.07 (–0.05, 0.18)
Q4 (42.9–58.4)	–0.22 (–0.29, –0.15)	0.22 (0.10, 0.33)	0.07 (–0.03, 0.18)
<i>P</i> trend	<0.0001	<0.001	0.17
<i>Mean PPD</i>			
Q1 (19.1–29.3)	Ref	Ref	Ref
Q2 (29.3–35.2)	–0.02 (–0.06, 0.02)	0.05 (0.01, 0.09)	0.06 (0.01, 0.10)
Q3 (35.2–42.9)	–0.16 (–0.21, –0.12)	0.12 (0.06, 0.18)	0.11 (0.05, 0.17)
Q4 (42.9–58.4)	–0.12 (–0.17, –0.08)	0.19 (0.13, 0.26)	0.15 (0.09, 0.22)
<i>P</i> trend	<0.0001	<0.0001	<0.0001

Table 3. Association between RFM and periodontal parameters. Model I: Adjusted for age, sex, and race. Model II: Model I additionally adjusted for marital status, smoking status, recreational activity, work activity, frequency of weekly use of floss/device, diabetes mellitus, and hypertension.

Subgroup	RFM				<i>P</i> for interaction
	Q1 (19.1–29.3)	Q2 (29.3–35.2)	Q3 (35.2–42.9)	Q4 (42.9–58.4)	
Age					0.01
≤60 years					
Case/participants	896/2010	729/1735	573/1816	660/1731	
OR (95%CI)	Ref	1.23 (1.00, 1.52)	1.67 (1.27, 2.19)	2.21 (1.64, 2.96)	
>60 years					
Case/participants	413/568	593/840	443/761	455/846	
OR (95%CI)	Ref	0.91 (0.59, 1.41)	0.94 (0.59, 1.51)	0.68 (0.41, 1.15)	
Sex					0.66
Male					
Case/participants	1296/2523	1187/2090	320/492	4/4	
OR (95%CI)	Ref	1.15 (0.94, 1.39)	1.54 (1.13, 2.09)	NA	
Female					
Case/participants	13/55	135/485	696/2085	1111/2573	
OR (95%CI)	Ref	1.28 (0.53, 3.09)	1.60 (0.69, 3.70)	1.78 (0.75, 4.23)	
Race					0.63
Whites					
Case/participants	418/1066	521/1218	407/1155	352/993	
OR (95%CI)	Ref	1.27 (0.97, 1.66)	1.70 (1.31, 2.22)	1.87 (1.34, 2.61)	
Others					
Case/participants	891/1512	801/1357	609/1422	763/1584	
OR (95%CI)	Ref	1.05 (0.87, 1.28)	1.30 (1.01, 1.69)	1.54 (1.13, 2.11)	

Table 4. Subgroup analyses of the associations between RFM and moderate/severe periodontitis by age, gender, and race. Adjusted for age, sex, race, marital status, smoking status, recreational activity, work activity, frequency of weekly use of floss/device, diabetes mellitus, and hypertension except the subgroup variable.

95% CI 0.62–0.87). However, in the fully adjusted model, the highest quartiles of RFM increased the risk of Stage III/IV periodontitis compared to quartiles1 (OR_{Q4vs1} = 1.36, 95% CI 1.01–1.83).

Discussion

In this cross-sectional study, we identified a non-linear positive relationship between RFM and periodontitis. The association was more pronounced when RFM was approximately 30–43. The stronger associations of RFM with periodontitis were observed in individuals younger than 60 years old. RFM may be suggested as a convenient and suitable measure of obesity for investigating the relationship between obesity and periodontitis. However, additional longitudinal trials are necessary to provide further evidence and support for our findings.

Increasing evidence indicates that obesity is a risk factor for periodontitis. Adipose tissue serves as a significant source of various pro-inflammatory mediators, while the reduced production of anti-inflammatory

adipokines results in a systemic imbalance between pro- and anti-inflammatory adipokines, leading to a sustained low-grade inflammatory state^{20,21}. In our previous study, we observed a J-shaped association between the SII and periodontitis¹⁸, suggesting a potential explanation for the inverse association trend between RFM and periodontitis when RFM is below 30. Furthermore, obesity leads to an increase in reactive oxygen species (ROS) and a decrease in antioxidant capacity²². Elevated levels of ROS can cause damage to DNA, lipids, and proteins in host cells, leading to cytotoxicity and accelerating the advancement of periodontitis²³.

BMI is currently the most commonly utilized tool for diagnosing obesity, reflecting overall obesity. Recent studies have found that central obesity is more strongly associated with disease than overall obesity, including periodontitis²⁴. As a result, several indices representing central obesity have been developed. Among these indices, RFM is easy to calculate, derived from waist circumference and height, and is sex-specific. It also performs well in estimating the proportion of total body fat, as validated by dual-energy X-ray absorptiometry (DXA)^{7,25}. In line with BMI and WC^{26–28}, we also found a positive association between RFM and periodontitis.

In subgroup analysis, a modifying effect of age on the relationship between RFM and periodontitis was observed. Additionally, a L-shaped association between RFM and periodontitis was noted in individuals under 60 years old, while older adults showed a negative association trend. Similar trends were also found between BMI and periodontitis^{28,29}. Individuals under 60 years old with a more active immune response had higher RFM, while the host immune response was not associated with RFM in older adults, which may be a contributing factor to this phenotype. Furthermore, the dilution of the effect of obesity was observed in the older age groups. It is possible that the relationship between obesity and the periodontal condition of older participants was overshadowed by stronger risk factors, such as age²⁸. However, it is still necessary to explore the molecular mechanism underlying the potential relationship between obesity and periodontitis in older adults.

This study presents several notable strengths. Firstly, the analysis was carried out on a substantial sample size, enhancing the reliability of the findings. Moreover, RFM is simpler to evaluate compared to DXA and does not involve radiation, making it more practical for use in clinical settings. Notably, the study is pioneering in uncovering a positive correlation between RFM and periodontal disease. Nevertheless, it is important to acknowledge various limitations that require consideration. Primarily, the cross-sectional design of the study precludes definitively establishing a causal relationship between RFM and periodontal health. Additionally, the study's data are specific to the U.S. population and may not be generalizable to other countries. In analytic epidemiology, achieving high internal validity is crucial. Therefore, future studies should prioritize this aspect over national representativeness of the data (external validity). Lastly, the presence of unmeasured variables impeded the full adjustment for all potential confounding factors. To address these limitations, future research endeavors should involve multi-center prospective trials to verify any potential causal associations.

Conclusions

RFM is positively associated with periodontitis in U.S. adults, particularly in those under 60 years old.

Data availability

The NHANES data of our study are openly available at <https://www.cdc.gov/nchs/nhanes/default.aspx>.

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Competing interests

The authors declare no competing interests.

Additional information

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