Lipids in Health and Disease

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The non-linear relationships between fat mass and lean body mass with arthritis

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Abstract

Introduction Body composition has been associated with various health outcomes, but its specific relationship with arthritis risk remains unclear. The study aimed to examine the associations between lean body mass (LBM) and fat mass (FM) with arthritis risk in men and women and to identify their threshold values.

Methods The data were obtained from the CHARLS, a prospective cohort study from 2011 to 2018. Multivariate Cox regression models evaluated the associations between LBM and FM and arthritis risk. Smoothing curves and two-piece linear regression models were applied to identify the inflection points of LBM and FM associated with arthritis risk.

Results A total of 6,761 participants were included in this study. During a mean follow-up period of 6.66 years, 944 participants (13.96%) developed new-onset arthritis, with an incidence rate of 20.72 per 1,000 person-years. Multivariate Cox regression analysis demonstrated a significant linear association between FM and the risk of new-onset arthritis in men. Individuals in the highest FM quartile (Q4) had the highest risk of developing arthritis (*HR* = 1.25, 95% *CI*: 1.03–1.51). Two-piece linear regression models revealed nonlinear relationships between LBM, FM, and arthritis risk. Specifically, in men, LBM was negatively associated with arthritis risk when it was below 43.79 kg (*HR* = 0.97, 95% *CI*: 0.95–0.99), but this association was no longer significant above this threshold (*HR* = 1.01, 95% *CI*: 0.98–1.03). In women, arthritis risk significantly decreased when LBM exceeded 39.04 kg (*HR* = 0.92, 95% *CI*: 0.87–0.96). Additionally, in women, FM exhibited a U-shaped relationship with arthritis risk, with the lowest risk observed at an FM level of 17.16 kg.

Conclusions Among Chinese adults aged 45 and older, maintaining appropriate levels of LBM and FM may help reduce arthritis risk. Based on the nonlinear findings, it is recommended to maintain LBM below 43.79 kg for men, above 39.04 kg for women, and to keep FM at approximately 17.16 kg for women, which may be appropriate.

Keywords Predicted lean body mass, Predicted fat mass, Arthritis, CHARLS, Cohort study

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Introduction

Arthritis is a chronic inflammatory condition primarily characterized by joint inflammation, synovial tissue swelling, and joint stiffness [1, 2]. Osteoarthritis and rheumatoid arthritis are the two most common types. In 2020, arthritis affected around 595 million individuals globally, accounting for 7.6% of the world's population [3]. In China, with the aging population, the number of individuals suffering from arthritis has exceeded 100 million, and this figure continues to grow [4, 5]. Although healthcare expenditures have been increasing, there has been minimal improvement in the quality of life for arthritis patients [6]. Therefore, identifying risk factors for arthritis and implementing early prevention measures may provide a more effective approach to addressing this health challenge.

Obesity, a global public health issue, has been strongly associated with the high prevalence of arthritis [7, 8]. Research suggests that obesity not only increases joint stress through mechanical overload but may also trigger chronic inflammation via endocrine and metabolic pathways, thereby exacerbating the risk of arthritis [9]. Currently, body mass index (BMI) is the most commonly used metric for assessing obesity; however, it has significant limitations, including its inability to differentiate between LBM and FM or to reflect the distribution of fat in different parts of the body [10]. Recent studies have highlighted the distinct effects of LBM and FM on musculoskeletal disorders [11–13]. For instance, a cross-sectional study posits that patients with early-stage arthritis experience a muscle mass loss rate four to five times higher than that of healthy individuals, while their average FM is approximately 4% higher than the normal population [14]. Similarly, Letarouilly et al. found that patients with rheumatoid arthritis exhibit significantly lower lean body mass and higher obesity rates compared to healthy individuals [15]. However, the specific role of LBM in arthritis remains inconsistent across studies. Karlsson et al. found that while LBM generally exerts a protective effect against arthritis, the negative impact of excess fat in persons with obesity may outweigh the protective benefits of muscle, thereby increasing the risk of arthritis [16, 17].

Existing epidemiological studies on the relationship between LBM and FM and arthritis have primarily employed cross-sectional designs, which are limited in establishing causal relationships. Moreover, most studies have not thoroughly investigated the independent effects of LBM and FM, and there is a notable lack of stratified analyses across different Sexs and age groups. The study utilized the China Health and Retirement Longitudinal Study (CHARLS) to systematically evaluate the independent effects of LBM and FM on the risk of arthritis incidence. To address the limitations of the high-cost dual-energy X-ray absorptiometry (DXA) method, this study utilized highly predictive anthropometric equations developed by Lee et al. to estimate FM and LBM [18]. This method has been proven to exhibit excellent predictive performance in epidemiological analyses and serves as a cost-effective alternative [19].

By combining a longitudinal study design with analyses based on nationally representative samples, this research not only addresses existing gaps in the literature but also provides novel scientific evidence for the early prevention and precise intervention of arthritis. We hypothesize that LBM exerts a protective effect against arthritis, but the negative impact of FM may offset or even outweigh this protective effect in persons with obesity. This study will offer valuable insights into the complex mechanisms through which body composition influences arthritis risk.

Materials and methods

Study population

Data for the research was sourced from the CHARLS database. CHARLS is a nationally representative longitudinal survey targeting adults aged 45 and above. It employs a multi-stage probability-proportional-to-size (PPS) sampling method to ensure national representativeness [20]. The survey was first conducted in 2011 using Computer-Assisted Personal Interviews (CAPI) and covers demographic characteristics, economic status, as well as health and functional information, with follow-up surveys conducted every 2 to 3 years. Blood sample data from CHARLS were collected in 2011 and 2015, including biomarkers such as blood glucose and blood lipids. All biomedical procedures were performed by certified professionals in strict accordance with international standards and laboratory protocols. Samples were preserved at an optimal temperature of 4 °C and promptly transported to the central laboratory in Beijing (Youanmen Clinical Laboratory Center, Capital Medical University) for diagnostic assessment. The study was approved by the Institutional Review Board (IRB) of the National School of Development at Peking University (IRB00001052-11015), and all participants provided informed consent before participation.

The baseline survey of this study began in 2011 (Wave 1), with 17,707 individuals completing both physical examinations and questionnaire assessments. Follow-up surveys were subsequently conducted in 2013 (Wave 2), 2015 (Wave 3), and 2018 (Wave 4). The study excluded the following individuals: those younger than 45 years ($n = 418$), individuals with conditions such as cancer or chronic liver disease that could potentially affect arthritis progression ($n = 313$), those with incomplete LBM and FM data ($n = 4,235$), those missing arthritis information ($n = 3,889$), and those diagnosed with arthritis at baseline

($n = 2{,}089$). In the end, 6,761 qualified participants were incorporated into the final analysis (Fig. 1).

Exposure variables

In this study, LBM and FM of participants were estimated using anthropometric prediction equations developed by Lee et al. [18]. These equations were selected due to their extensive application and validation across multiple populations, demonstrating high reliability and accuracy. Given that the study's population was Asian, the race variable in the models was modified based on prior research [19]. For men, the race variable in the LBM and FM prediction equations was modified to−1.007 and 1.050, respectively, while for women, it was adjusted to−0.34 and 0.325, reflecting the unique biological characteristics of Asian populations. The LBM and FM values for all participants were calculated using the following formulas:

Female

$$\text{Fat Mass (kg)} = 11.817 + 0.041 \times \text{age (years)} - 0.199 \times \text{height (cm)} + 0.610 \times \text{weight (kg)} + 0.044 \times \text{WC (cm)} + 0.325$$

$$\text{Lean Body Mass (kg)} = -10.683 - 0.039 \times \text{age (years)} + 0.186 \times \text{height (cm)} + 0.383 \times \text{weight (kg)} - 0.043 \times \text{WC (cm)} - 0.340$$

Male

$$\text{Fat Mass (kg)} = -18.592 - 0.009 \times \text{age (years)} - 0.080 \times \text{height (cm)} + 0.226 \times \text{weight (kg)} + 0.387 \times \text{WC (cm)} + 1.050$$

$$\text{Lean Body Mass (kg)} = 19.363 + 0.001 \times \text{age (years)} + 0.064 \times \text{height (cm)} + 0.756 \times \text{weight (kg)} - 0.366 \times \text{WC (cm)} - 1.007$$

Assessment of incident arthritis

At both baseline and follow-up surveys, participants were asked "Have you been diagnosed with arthritis by a doctor?" Those who answered "yes" were classified as arthritis patients. Participants who reported having arthritis at baseline in 2011 were excluded. If a participant was diagnosed with arthritis during follow-up periods in 2013,

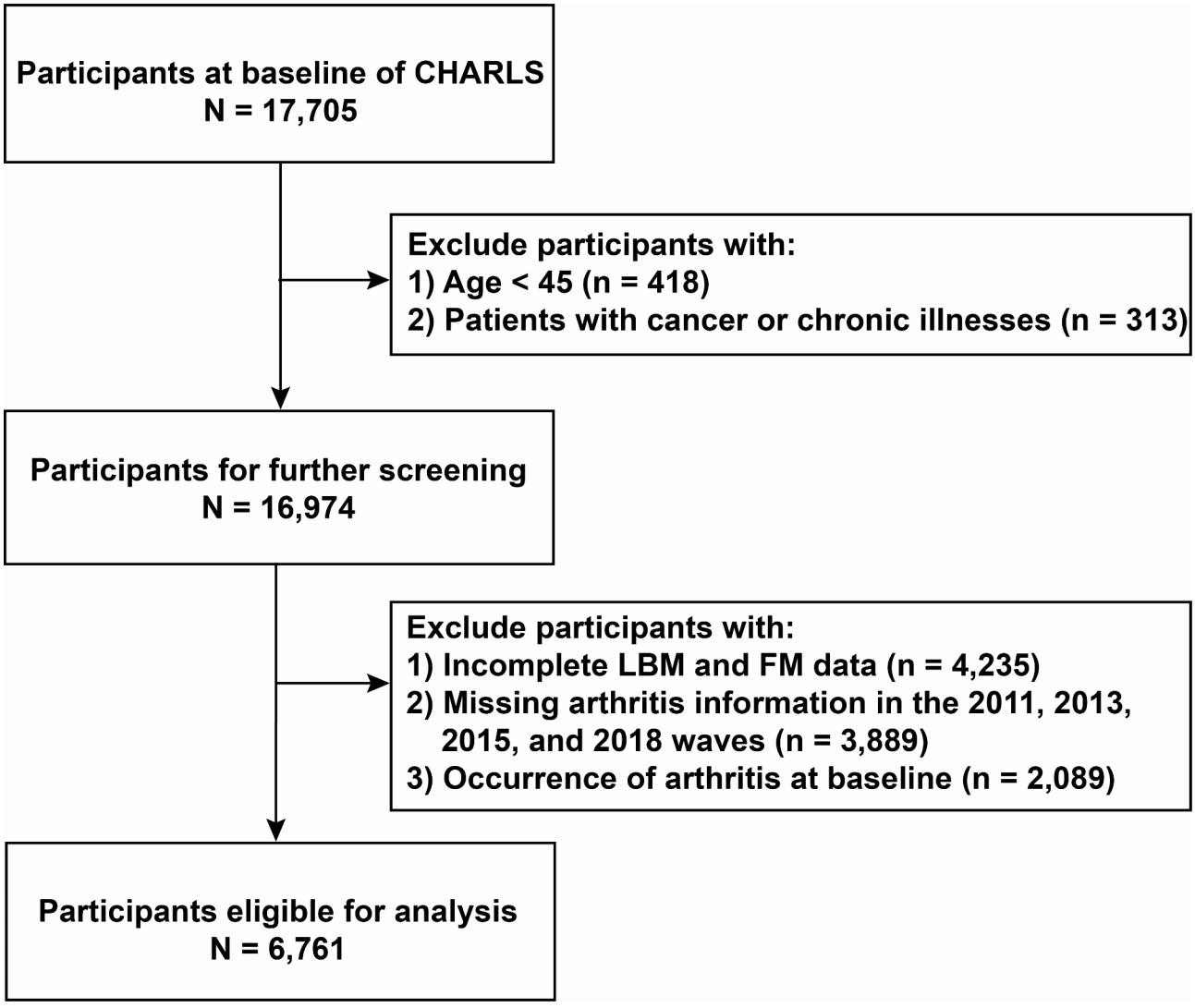

Fig. 1 Research and design flow chart

2015, or 2018, they were classified as incident arthritis cases according to the definition of new-onset arthritis.

Covariates

In this study, trained medical staff collected sociodemographic data, including age, sex, marital status, Location, and educational level using a standardized questionnaire. Behavioral factors, such as participation in social activities, sleep duration, smoking history, and alcohol consumption history, were recorded through self-administered questionnaires. Physical measurements, including waist circumference (WC), height, and weight, were obtained to ensure standardized and accurate data collection. BMI was calculated as weight (kg) divided by the square of height (m^2). Additionally, information on current health conditions, including hypertension and diabetes, was collected. Professional medical personnel collected blood samples from the forearm vein following a minimum of eight hours of fasting. Biochemical parameters include C-reactive protein (CRP), low-density lipoprotein cholesterol (LDL-C), total cholesterol (TC), and high-density lipoprotein cholesterol (HDL-C).

Statistical analysis

The statistical analysis was conducted using R software (version 4.3.2) and EmpowerStats software (version 4.1). Continuous variables were reported as the mean ± standard deviation or the median with interquartile range, depending on their distribution characteristics. Group comparisons were conducted using the t-test or Mann-Whitney U test, as appropriate. Categorical variables were described as frequencies (%) and compared using the $\chi 2$ test. Before conducting correlation analyses, all predictor variables were examined for multicollinearity using the variance inflation factor (VIF). Variables with VIF values exceeding 5 were excluded to address potential multicollinearity issues. Multivariable Cox regression models were employed to investigate the associations between FM, LBM, and the risk of arthritis, with mutual adjustment for these two variables to assess their independent effects. Segmented linear regression and smoothing curve analyses were employed to further explore potential nonlinear relationships between LBM, FM, and arthritis risk. Subgroup analyses were conducted to determine whether sociodemographic factors moderated the associations between LBM, FM, and arthritis risk. A *P*-value less than 0.05 was considered to indicate statistical significance.

Results

General characteristics of participants

The study included 6,761 participants, 944 of whom were identified as having incident arthritis. Compared to individuals without arthritis, those with arthritis were older, had a higher proportion of women, lower educational levels, and lower participation in social activities. They also had shorter sleep duration, a higher prevalence of smoking and alcohol consumption history, and were more likely to reside in rural areas. Additionally, participants with arthritis exhibited significantly higher levels of TC, and FM, while LBM was significantly lower ($P < 0.05$). (Table 1). There were no significant differences in Diabetes, BMI, WC, CRP, TC, HDL-C, and LDL-C between the included and excluded participants (Supplementary Table 3). The characteristics of the population with baseline arthritis and those excluded due to missing FM and LBM data (Supplementary Tables 4–6).

Association between LBM, FM, and arthritis risk

The results of covariate selection are presented in Supplementary Table 7. Due to collinearity issues, weight, WC, and BMI were excluded from the multivariate Cox regression model. After adjusting for potential confounding factors and stratifying by sex, the results are summarized in Table 2. Compared to the Q1 group, individuals in the highest FM quartile (Q4) had an increased risk of arthritis by 25% in men (*HR* = 1.25, 95% *CI*: 1.03–1.51) and 71% in women (*HR* = 1.71, 95% *CI*: 1.20–2.43). Conversely, individuals in the highest LBM quartile (Q4) exhibited a reduced risk of arthritis by 20% in men (*HR* = 0.80, 95% *CI*: 0.65–0.99) and 28% in women (*HR* = 0.68, 95% *CI*: 0.52–0.88). Additionally, Fig. 2; Table 3 illustrate the results of the smoothed curve fitting, and the two-segment linear regression model. In men, FM was linearly associated with an increased risk of arthritis (*P* for nonlinear > 0.05). In contrast, in women, FM exhibited a U-shaped relationship with arthritis risk, with the lowest risk observed when FM was 17.16 kg (Fig. 2C). For LBM, the analysis revealed sex-specific threshold effects. In men, the inflection point was identified at 43.79 kg. When LBM was below 43.79 kg, it was significantly negatively associated with arthritis risk (*HR* = 0.97, 95% *CI*: 0.95–0.99). However, when LBM exceeded 43.79 kg, this association was no longer significant (*HR* = 1.01, 95% *CI*: 0.98–1.03) (Fig. 2B). In women, the inflection point for LBM was 39.04 kg. When LBM was below 39.04 kg, its association with arthritis risk was not statistically significant (*HR* = 1.10, 95% *CI*: 0.94–1.30). However, when LBM exceeded 39.04 kg, arthritis risk significantly decreased (*HR* = 0.92, 95% *C*I: 0.87–0.96) (Fig. 2D).

Subgroup analysis

The results of the subgroup analysis indicated that age groups, BMI categories, smoking history, alcohol consumption history, hypertension, and diabetes did not significantly influence the predictive effect of LBM and FM on arthritis risk in both men and women (all P for interaction > 0.05) (Tables 4 and 5).

Table 1 Baseline characteristics of the study population

Variables	Total *N* = 6761	Non-Arthritis *N* = 5817	Arthritis *N* = 944	*P* value
Age (years)	64.93 (9.53)	65.05 (9.60)	64.21 (9.06)	**0.010**
Sex (%)				**< 0.001**
Men	3350 (49.55)	2935 (50.46)	415 (43.96)	
Women	3411 (50.45)	2882 (49.54)	529 (56.04)	
Height (cm)	159.00 (153.00, 165.00)	159.10 (153.20, 165.20)	157.50 (151.88, 163.90)	**< 0.001**
Weight (kg)	58.40 (51.70, 66.20)	58.40 (51.90, 66.30)	58.30 (51.30, 65.53)	0.205
WC (cm)	84.80 (78.00, 92.00)	84.80 (78.00, 92.00)	84.50 (78.00, 92.00)	0.904
BMI (kg/m^2)	23.47 (3.63)	23.44 (3.62)	23.68 (3.67)	0.062
Sleep time (h)	7.33 (1.73)	7.34 (1.73)	7.21 (1.74)	**0.032**
Marital status (%)				0.171
Married	6022 (89.07)	5169 (88.86)	853 (90.36)	
Unmarried	739 (10.93)	648 (11.14)	91 (9.64)	
Educational Level (%)				**< 0.001**
Primary school	1719 (25.43)	1436 (24.69)	283 (29.98)	
Middle school	2638 (39.02)	2248 (38.65)	390 (41.31)	
High school and above	2404 (35.56)	2133 (36.67)	271 (28.71)	
Alcohol history (%)				**0.023**
Yes	4465 (66.04)	3811 (65.51)	654 (69.28)	
No	2296 (33.96)	2006 (34.49)	290 (30.72)	
Smoking history (%)				**0.018**
Yes	4031 (59.62)	3435 (59.05)	596 (63.14)	
No	2730 (40.38)	2382 (40.95)	348 (36.86)	
Social Activities (%)				**0.018**
Yes	3218 (47.60)	2735 (47.02)	483 (51.17)	
No	3543 (52.40)	3082 (52.98)	461 (48.83)	
Location (%)				**< 0.001**
Urban	614 (9.08)	565 (9.71)	49 (5.19)	
Rural	6147 (90.92)	5252 (90.29)	895 (94.81)	
Hypertension (%)				0.133
Yes	2613 (38.65)	2269 (39.01)	344 (36.44)	
No	4148 (61.35)	3548 (60.99)	600 (63.56)	
Diabetes (%)				0.448
Yes	721 (10.66)	627 (10.78)	94 (9.96)	
No	6040 (89.34)	5190 (89.22)	850 (90.04)	
CRP (mg/dl)	0.99 (0.53, 2.04)	1.00 (0.53, 2.06)	0.95 (0.51, 1.96)	0.221
TC (mg/dl)	192.33 (175.13, 203.35)	192.33 (168.85, 195.91)	192.33 (175.13, 203.74)	**0.043**
HDL-C (mg/dl)	48.71 (43.30, 54.90)	48.71 (43.30, 54.90)	48.71 (42.91, 55.28)	0.557
LDL-C (mg/dl)	115.89 (101.29, 126.80)	115.89 (96.55, 123.91)	115.89 (101.68, 126.80)	0.083
FM (kg)	19.20 (6.83)	19.13 (6.84)	19.64 (6.74)	**0.033**
LBM (kg)	38.96 (8.21)	39.07 (8.16)	38.27 (8.47)	**0.005**

Abbreviations: WC waist; BMI, Body Mass Index; CRP, C-reactive protein; TC, Total Cholesterol; HDL-C, High-Density Lipoprotein Cholesterol; LDL-C, Low-Density Lipoprotein Cholesterol; FM, Fat Mass; LBM, Lean Body Mass

Subgroup analysis

Sensitivity analyses were carried out to validate the multivariate analysis results of Model 3 and assess their stability. In this study, the stepwise Cox regression model selection method was employed. Both forward selection and backward elimination yielded consistent results (Supplementary Table 8). When these variables were included in the model, the results generated by Cox regression analysis were consistent with the main analysis (Supplementary Table 9).

Discussion

This study investigated the relationship between FM, LBM, and arthritis risk in a Chinese population. Overall, an increase in FM was significantly associated with a higher risk of arthritis in men, whereas in women, FM exhibited a U-shaped relationship with arthritis risk, with the lowest risk observed at an FM level of 17.16 kg. Additionally, in women, an LBM exceeding 39.04 kg was associated with a significantly reduced risk of arthritis. In

Table 2 Hazard ratios for incident arthritis by predicted LBM and FM

Variable	Event, *n* (%)	Model1	*P*	Model2	*P*	Model3	*P*
Man							
FM							
Q1	101 (12.05)	reference		reference		reference	
Q2	99 (11.83)	1.15 (0.96, 1.39)	0.1347	1.08 (0.96, 1.22)	0.1828	1.12 (0.91, 1.38)	0.2650
Q3	98 (11.69)	1.26 (1.05, 1.52)	0.0135	1.18 (1.06, 1.33)	0.0036	1.24 (1.00, 1.55)	0.0534
Q4	117 (13.98)	1.27 (1.05, 1.53)	0.0116	1.20 (1.07, 1.34)	0.0017	1.25 (1.03, 1.51)	0.0248
P for trend		0.0053		0.0216		0.0167	
LBM							
Q1	103 (12.29)	reference		reference		reference	
Q2	111 (13.26)	0.90 (0.74, 1.11)	0.2493	0.93 (0.76, 1.11)	0.3622	0.93 (0.77, 1.13)	0.4664
Q3	102 (12.18)	0.74 (0.61, 0.90)	0.0024	0.76 (0.62, 0.93)	0.0007	0.80 (0.65, 0.98)	0.0024
Q4	99 (11.81)	0.71 (0.59, 0.87)	0.0008	0.74 (0.60, 0.91)	0.0050	0.80 (0.65, 0.99)	0.0439
P for trend		0.0001		0.0012		0.0181	
Female							
FM							
Q1	133 (15.59)	reference		reference		reference	
Q2	122 (14.32)	0.97 (0.80, 1.42)	0.7822	1.01 (0.81, 1.26)	0.9414	1.03 (0.82, 1.29)	0.8134
Q3	131 (15.26)	1.14 (0.91, 1.42)	0.2520	1.21 (0.94, 1.57)	0.1418	1.25 (0.96, 1.62)	0.0963
Q4	143 (16.76)	1.35 (1.00, 1.82)	0.0473	1.66 (1.18, 2.34)	0.0037	1.71 (1.20, 2.43)	0.0027
P for trend		0.0350		0.0036		0.0025	
LBM							
Q1	148 (17.35)	reference		reference		reference	
Q2	121 (14.20)	0.89 (0.75, 1.07)	0.2306	0.86 (0.71, 1.05)	0.1350	0.91 (0.73, 1.14)	0.4139
Q3	131 (15.36)	0.79 (0.60, 1.05)	0.0994	0.75 (0.55, 1.03)	0.0759	0.72 (0.50, 1.03)	0.0718
Q4	129 (15.12)	0.77 (0.63, 0.95)	0.0161	0.74 (0.59, 0.93)	0.0112	0.68 (0.52, 0.88)	0.0042
P for trend		0.0200		0.0167		0.0026	

Model 1: Unadjusted. Model 2: Adjusted for age, educational level, and marital status. Model 3: Model 2 plus height, drinking history, smoking history, social activities, location, sleep time, hypertension, diabetes, TC, HDL-C, and LDL-C. Note: Both LBM and FM were mutually adjusted for each other

men, a lower arthritis risk was observed when LBM was below 43.79 kg; however, this association was no longer significant when LBM exceeded this threshold.

Obesity is commonly recognized as a major risk factor for arthritis, particularly osteoarthritis [21, 22]. The primary pathogenic mechanisms include increased joint load and inflammation triggered by obesity-related pathways [23–25]. However, BMI, as a ratio of weight to height, does not distinguish between fat mass and LBM, which may lead to inaccurate risk assessments for individuals. For example, at the same BMI level, the risk of arthritis may differ significantly between athletes and non-athletes, as well as between men and women. Therefore, investigating the relationship between body composition factors based on BMI, such as LBM and FM, and arthritis risk is of great importance for more accurately assessing this risk.

Previous studies have demonstrated that predicted LBM and FM are effective surrogate markers for assessing body composition. These predicted indices show high consistency with actual LBM and FM values measured using DXA. They have been widely applied to examine the effect of body composition on all-cause mortality, cardiovascular disease, cause-specific mortality, and lung cancer risks, as well as to explain the obesity paradox [26–29]. However, research on the relationship between body composition and arthritis risk remains limited, and the findings are inconsistent. Existing evidence indicates that LBM and FM have significantly different effects on joint health. Specifically, excessive FM may increase arthritis symptoms and risk by promoting the release of inflammatory cytokines [30, 31]. Particularly in weight-bearing joints such as the knees and hips, an increase in FM exacerbates the risk of arthritis through mechanical stress and inflammatory responses [32]. In contrast, LBM, which primarily consists of muscle and bone, contributes to reducing joint stress and enhancing joint stability [33, 34]. Nevertheless, studies on the link between LBM and arthritis risk have yielded inconsistent results. For example, research by Notarnicola et al. suggested that a higher LBM may increase the risk of arthritis in persons with overweight or obesity [35]. This discrepancy could be attributed to the lack of adjustment for FM, as the negative impact of excess fat may outweigh the protective effect of muscle. In comparison, the present study, by adjusting for FM, is the first to comprehensively reveal the independent association between LBM and arthritis risk. Additionally, the longitudinal design

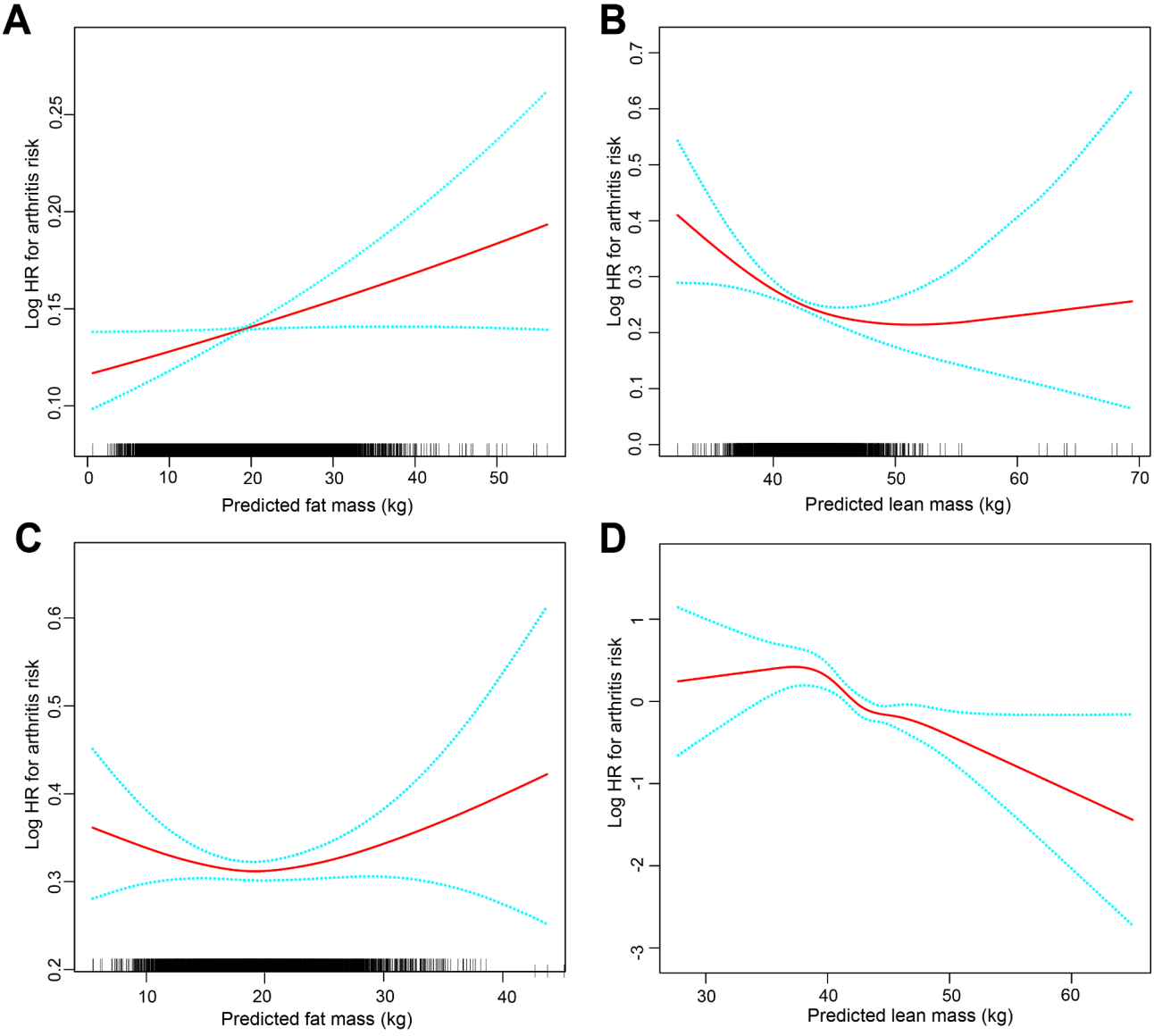

Fig. 2 Smoothed curve fitting was used to evaluate the nonlinear relationship between (**A**) men FM, (**B**) men LBM, (**C**) women FM, and (**D**) women LBM and the risk of arthritis. Adjusted for age, educational level, marital status, height, drinking history, smoking history, social activities, location, sleep time, hypertension, diabetes, TC, HDL-C, and LDL-C. Note: Both LBM and FM were mutually adjusted for each other

of this study, with follow-up from 2011 to 2018, provides a more detailed analysis of the enduring effects of LBM and FM on arthritis risk compared to the cross-sectional design employed by Notarnicola et al. This offers important insights into the intricate connection between body composition and the incidence of arthritis.

Smoothing curve analysis and threshold effect analysis revealed a nonlinear relationship between LBM and arthritis risk. In men, the protective effect of LBM plateaued when it reached 43.79 kg. In women, however, a significant protective effect only became apparent when LBM exceeded 39.04 kg. This result aligns with the results of Kon et al., who observed that men typically have higher LBM levels, leading to a higher saturation threshold for the protective effect. In contrast, women have lower baseline LBM levels, requiring them to reach a specific threshold before experiencing protective effects [36]. Additionally, the adverse effects of declining estrogen levels on joint and bone health in postmenopausal women may be partially offset by increased LBM, which explains the more pronounced protective effect observed when LBM exceeds 39.04 kg in women [37, 38]. The findings of this study indicate a significant sex-specific difference in the association between FMand the risk of arthritis. Specifically, in men, FM demonstrated a linear positive correlation with arthritis risk, meaning that an increase in FM was consistently associated with a higher likelihood of developing arthritis. In contrast, in women,

Table 3 Thresholds for the association between predicted LBM and FM with arthritis risk

Variables	Men	Women	
	LBM (HR, 95% CI)	FM (HR, 95% CI)	LBM (HR, 95% CI)
Fitting model by two-piecewise linear regression			
Inflection point (kg)	43.79	17.16	39.04
≤ Inflection point	0.97 (0.95, 0.99)	0.98 (0.95,1.00)	1.10 (0.94, 1.30)
> Inflection point	1.01 (0.98, 1.03)	1.01 (1.00,1.03)	0.92 (0.87, 0.96)
***P*for log-likelihood ratio test**	0.037	0.022	0.024

Adjusted for age, educational level, marital status, height, drinking history, smoking history, social activities, location, sleep time, hypertension, diabetes, TC, HDL-C, and LDL-C. Note: Both LBM and FM were mutually adjusted for each other

FM exhibited a U-shaped relationship with arthritis risk, suggesting that while an optimal level of FM may confer protective effects on joint health, excessive FM could increase the risk of arthritis. These results are supported by previous studies. For instance, research conducted by Ruiz-Fernandez et al. reported that an appropriate amount of FM may reduce arthritis risk, whereas excessive adiposity may exacerbate joint damage by promoting the secretion of pro-inflammatory cytokines such as IL–6. Conversely, insufficient fat levels may lead to metabolic dysfunction, thereby increasing the susceptibility to arthritis [39]. This perspective has been corroborated by other studies [40, 41]. Moreover, sex-based differences in fat distribution may further contribute to the observed disparities in arthritis risk. Women generally have a higher proportion of subcutaneous fat, which may play a protective role by cushioning joints and reducing mechanical stress. In contrast, men tend to have a higher proportion of visceral fat, which has been strongly linked to metabolic syndrome and an elevated risk of arthritis [42, 43].

In conclusion, our findings align with previous research, further underscoring the crucial role of body composition in the pathogenesis of arthritis. These findings not only enhance our understanding of the relationship between FM and arthritis risk but also highlight the importance of considering sex-specific characteristics in arthritis prevention and management. Tailored weight control and body composition management strategies should be implemented to mitigate the risk of arthritis effectively.

Study strengths and limitations

The strengths include the broad representativeness of the data, particularly the CHARLS database, which provides detailed information on adults aged 45 and older in China. This dataset offers unique insights into the risk factors for arthritis within this population. Additionally,

Table 4 Stratified analysis of predicted LBM and FM with arthritis risk in women

Subgroup	FM		LBM	
	HR (95% CI)	*P* for interaction	HR (95% CI)	*P* for interaction
Age		0.292		0.766
< 60	1.05(1.00, 1.08)		1.01 (0.99, 1.03)	
60–75	1.04(1.01, 1.07)		1.00 (0.99, 1.02)	
> 75	1.04(1.00, 1.09)		1.01 (0.97, 1.05)	
BMI		0.204		0.246
< 18.5	0.96(0.84, 1.09)		0.92 (0.81, 1.04)	
18.5–25	1.03(1.00, 1.07)		0.99 (0.97, 1.02)	
> 25	1.05(1.02, 1.08)		1.01 (0.99, 1.03)	
Smoking		0.962		0.755
Yes	1.04(1.00, 1.08)		1.01 (1.00, 1.02)	
No	1.04(1.02, 1.06)		1.01 (0.98, 1.05)	
Drinking		0.287		0.406
Yes	1.04(1.02, 1.07)		1.01 (1.00, 1.02)	
No	1.01(0.95, 1.07)		0.99 (0.96, 1.03)	
Hypertension		0.156		0.233
Yes	1.05(1.03, 1.07)		1.02 (1.00, 1.03)	
No	1.04(1.01,1.06)		1.00 (0.99, 1.02)	
Diabetes		0.367		0.837
Yes	1.07(1.00, 1.14)		1.01 (1.00, 1.02)	
No	1.04(1.02, 1.06)		1.01 (0.98, 1.04)	

Adjusted for age, educational level, marital status, height, drinking history, smoking history, social activities, location, sleep time, hypertension, diabetes, TC, HDL-C, and LDL-C. Note: Both LBM and FM were mutually adjusted for each other

Table 5 Stratified analysis of predicted LBM and FM with arthritis risk in men

Subgroup	FM		LBM	
	HR(95%CI)	*P* for interaction	HR(95%CI)	*P* for interaction
Age		0.473		0.255
< 60	1.01 (0.99, 1.03)		0.98(0.96, 1.01)	
60–75	1.01 (1.00, 1.03)		0.97(0.96, 0.99)	
> 75	1.03 (1.00, 1.05)		1.01(0.97, 1.06)	
BMI		0.166		0.423
< 18.5	0.99 (0.97, 1.01)		0.95(0.88, 1.02)	
18.5–25	1.01 (1.00, 1.03)		0.97(0.95, 0.99)	
> 25	1.04 (1.00, 1.11)		0.99(0.96, 1.01)	
Smoking		0.986		0.579
Yes	1.01 (1.00, 1.02)		0.99(0.97, 1.01)	
No	1.01 (1.00, 1.02)		0.98(0.96, 0.99)	
Drinking		0.066		0.364
Yes	1.02 (1.01, 1.03)		0.99(0.97, 1.00)	
No	1.01 (1.00, 1.01)		0.97(0.96, 0.99)	
Hypertension		0.682		0.878
Yes	1.04 (1.01, 1.07)		0.98(0.97, 1.00)	
No	1.04 (1.00, 1.07)		0.98(0.96, 1.00)	
Diabetes		0.449		0.280
Yes	1.04 (1.02, 1.06)		0.98(0.97, 0.99)	
No	1.06 (1.00, 1.13)		1.00(0.96, 1.04)	

Adjusted for age, educational level, marital status, height, drinking history, smoking history, social activities, location, sleep time, hypertension, diabetes, TC, HDL-C, and LDL-C. Note: Both LBM and FM were mutually adjusted for each other

the prospective cohort design enables stronger inferences about causal relationships between FM, LBM, and arthritis risk. Predicted FM and LBM are easy to obtain and cost-effective, making them suitable for large-scale screening. This study provides a new perspective for individualized assessment of arthritis risk in populations stratified by sex and BMI, and it offers evidence for the development of clinical interventions.

However, this study has several limitations. First, the use of anthropometric equations to calculate LBM and FM may not fully reflect actual values. Although Lee et al.'s equations account for racial effects, their reliability for Asian populations requires further validation. Second, due to data limitations, the study could not completely control for confounding factors such as diet, lifestyle, and genetic background. Third, the study population was limited to Chinese adults aged 45 years and older, and future research is needed to verify the generalizability of the findings across other ethnic groups and age ranges. Moreover, in the CHARLS database, the diagnosis of arthritis is based on self-reported information from patients and does not distinguish between specific subtypes, such as osteoarthritis and rheumatoid arthritis. Given the distinct pathophysiological mechanisms of these two conditions, obesity may influence their onset and progression through different pathways. For instance, osteoarthritis is primarily associated with mechanical load and cartilage degeneration, whereas rheumatoid arthritis may be affected by obesity-induced systemic inflammation. Consequently, this study is unable to conduct a detailed analysis of different arthritis subtypes. Future studies should incorporate more precise measurement tools, such as DXA, to validate these findings in diverse populations.

Conclusion

This study revealed a nonlinear relationship between LBM, FM, and the risk of incident arthritis. Maintaining an LBM below 43.79 kg for men and above 39.04 kg for women was associated with a reduced risk of arthritis. Similarly, in women, an FM level around 17.16 kg was associated with the lowest arthritis risk. These findings provide important guidance for both clinical and nursing practices. Clinicians can help patients reduce arthritis risk by increasing skeletal muscle mass (through resistance training) and controlling fat mass (through dietary management). Nursing staff can contribute by conducting health education, guiding patients to engage in regular exercise, adopting balanced diets, and maintaining a healthy body weight, thereby achieving effective arthritis prevention.

Abbreviations

CHARLS	The China Health and Retirement Longitudinal Study
LBM	Lean body mass
FM	Fat mass
IQR	Interquartile range
SD	Standard deviation
BMI	Body mass index
CRP	C-reactive protein
HR	Hazard Ratio
CI	Confidence interval

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12944-025-02525-6.

Supplementary Material 1

Acknowledgements
We are grateful to Peking University for offering open access to their data resources and to all the investigators who contributed to this study.

Author contributions
A.H conceptualized the study and conducted data analysis. Z.X, Z.C, Y.L, and J.C contributed to manuscript drafting. Z.X performed formal analysis and investigation. Z.C was responsible for validation. J.C also contributed to the conceptualization of the study. Y.C and X.Z critically reviewed and edited the manuscript. All authors contributed to and approved the final version of the article.

Funding
This study was supported by the Scientific and Technological Research and Development Program of Yan'an City, Shaanxi Province (No. 2016HM-04-04).

Data availability
The analysis in this study utilized publicly available datasets accessible at http://charls.pku.edu.cn.

Declarations

Ethics approval and consent to participate
This cohort study utilized data from the CHARLS database. Patient information was anonymized before analysis. The original CHARLS study received approval from the Ethical Review Committee of Peking University (IRB00001052–11015), with all participants providing informed consent at the time of their enrollment. This research adheres to the principles outlined in the Declaration of Helsinki.

Competing interests
The authors declare no competing interests.

Received: 29 December 2024 / Accepted: 11 March 2025
Published online: 01 April 2025

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