Postprint: Association Between Different Adiposity Measures and Frailty Among Older Adults in Rural Northwest China

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Abstract

Background Frailty is an age-related geriatric syndrome, and the prevalence of frailty among older adults in China is high and shows an increasing trend year by year. Obesity is closely related to the occurrence and development of multiple diseases, but its association with frailty remains controversial, which may be due to certain limitations of traditional obesity indicators in identifying fat distribution. Therefore, exploring the association between multiple obesity indicators and frailty is of great significance for further investigating the pathogenesis of frailty and developing preventive interventions.

Objective This study aims to explore the correlation between multiple obesity indicators and frailty in older adults, providing a scientific basis for the early prevention and control of frailty in this population.

Methods This study surveyed a total of 1,429 older adults aged 60 years and above in 6 rural areas of Jingyuan County, Gansu Province from March to May 2023. After further exclusion, 1,153 individuals were finally included. The FRAIL scale was used to assess frailty status in older adults. Waist circumference and BMI were grouped according to Chinese obesity standards, while waist-to-hip ratio (WHR), waist-to-height ratio (WHtR), body roundness index (BRI), and Chinese visceral adiposity index (CVAI) were grouped by quartiles. Multivariate Logistic regression, restricted cubic spline (RCS), and receiver operating characteristic (ROC) curves were used to explore the correlation between different obesity indicators and frailty.

Results This study included a total of 1,153 older adults aged 60 years and above, including 474 males (41.11%) and 679 females (58.89%), with a mean age of (70.86$±$4.76) years. According to FRAIL scale scores, there were 226 frail older adults and 927 non-frail older adults, with a frailty

prevalence of 19.60%. After adjusting for relevant variables, multivariate binary Logistic regression analysis showed that central obesity, moderate to severe obesity (with normal BMI as reference), Q3 and Q4 levels of WHR, and Q4 levels of WHtR, BRI, and CVAI (all with Q1 as reference) were risk factors for frailty in older adults (P<0.05). Moreover, with increasing levels of waist circumference, BMI, WHR, WHtR, BRI, and CVAI, the risk of frailty showed an upward trend (P for trend<0.05). RCS curve results showed that waist circumference, BMI, WHtR, BRI, and CVAI were positively correlated with frailty risk in older adults (P for linearity<0.05). ROC curve analysis showed that the areas under the curve (AUC) for waist circumference, BMI, WHR, WHtR, BRI, and CVAI in predicting frailty risk were 0.557 (95%CI=0.515~0.598), 0.570 (95%CI=0.528~0.612), 0.558 (95%CI=0.515~0.600), 0.610 (95%CI=0.568~0.652), 0.610 (95%CI=0.568~0.652), and 0.586 (95%CI=0.546~0.626), respectively, all showing predictive value for frailty risk (P<0.05). Among them, the AUCs of WHtR, BRI, and CVAI for predicting frailty risk were higher than that of waist circumference (Z=-5.443, P<0.001; Z=-5.443, P<0.001; Z=-2.595, P=0.009), and the AUCs of WHtR and BRI were higher than that of BMI (Z=-2.885, P=0.004; Z=-2.884, P=0.004).

Conclusion In older adults aged 60 years and above in rural northwestern China, obesity indicators including waist circumference, BMI, WHR, WHtR, BRI, and CVAI are positively correlated with frailty risk, among which WHtR and BRI demonstrate better predictive ability for frailty in older adults.

Full Text

The Relationship between Different Obesity Indicators and Frailty among the Elderly in Rural Northwest Regions

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Abstract

Background: Frailty is an age-related geriatric syndrome with notably high and rising prevalence among Chinese older adults. While obesity is closely associated with numerous diseases, its relationship with frailty remains controversial, potentially due to limitations of conventional obesity indicators in characterizing adipose tissue distribution. Investigating associations between multiple

adiposity metrics and frailty is crucial for advancing understanding of frailty pathogenesis and developing preventive interventions.

Objective: This study examines the relationship between various obesity indicators and frailty among older adults to provide scientific evidence for early frailty prevention and control.

Methods: From March to May 2023, we surveyed 1,429 elderly individuals aged 60 years and above across six rural villages in Jingyuan County, Gansu Province. After exclusions, 1,153 participants were included in the final analysis. Frailty status was assessed using the FRAIL scale. Waist circumference and BMI were categorized according to Chinese obesity criteria, while waist-to-hip ratio (WHR), waist-to-height ratio (WHtR), body roundness index (BRI), and Chinese visceral adiposity index (CVAI) were grouped by quartiles. Multivariate logistic regression, restricted cubic splines (RCS), and receiver operating characteristic (ROC) curve analyses were employed to explore associations between different obesity indicators and frailty.

Results: Among 1,153 participants (mean age 70.86$±$4.76 years; 474 males [41.11%] and 679 females [58.89%]), 226 were identified as frail and 927 as non-frail, yielding a frailty prevalence of 19.60%. Adjusted multivariate logistic regression revealed that central obesity, moderate-to-severe obesity (vs. normal BMI), Q3 and Q4 levels of WHR, and Q4 levels of WHtR, BRI, and CVAI (all vs. Q1) were significant risk factors for frailty (P<0.05). Risks increased progressively with higher levels of waist circumference, BMI, WHR, WHtR, BRI, and CVAI (P-trend<0.05). RCS analysis showed linear positive associations between waist circumference, BMI, WHtR, BRI, CVAI and frailty risk (P-linear<0.05). ROC analysis demonstrated predictive capacity for all indicators: waist circumference AUC=0.557 (95%CI=0.515-0.598), BMI AUC=0.570 (95%CI=0.528-0.612), WHR AUC=0.558 (95%CI=0.515-0.600), WHtR AUC=0.610 (95%CI=0.568-0.652), BRI AUC=0.610 (95%CI=0.568-0.652), and CVAI AUC=0.586 (95%CI=0.546-0.626) (all P<0.05). WHtR, BRI, and CVAI showed superior predictive ability compared to waist circumference (Z=-5.443, P<0.001; Z=-5.443, P<0.001; Z=-2.595, P=0.009), while WHtR and BRI outperformed BMI (Z=-2.885, P=0.004; Z=-2.884, P=0.004).

Conclusion: Among rural elderly aged $ $60 years in Northwest China, obesity indicators including waist circumference, BMI, WHR, WHtR, BRI, and CVAI were positively associated with frailty risk. WHtR and BRI demonstrated superior predictive performance compared to traditional indicators, offering valuable tools for early risk identification and targeted interventions.

Keywords: Frailty; Obesity; Aged; Waist circumference; Body mass index; Waist-to-height ratio; Body roundness index; Chinese visceral adiposity index; Northwest rural area

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Frailty is an age-related geriatric syndrome characterized by declines in physi-

ological function across muscular, metabolic, and immune systems, leading to decreased stress resistance and increased vulnerability. It significantly elevates risks of falls, disability, hospitalization, and mortality among older adults. Current estimates indicate that 16.0% (95%CI=12.0%-20.0%) of Chinese adults aged 60+ years are frail, with prevalence rising annually and substantially higher rates in rural versus urban areas.

Obesity is a metabolic disease whose health risks depend not only on total fat mass but critically on fat distribution patterns. While previous studies have demonstrated positive associations between obesity and frailty risk, contradictory findings exist. For instance, research by JAYANAMA et al. suggested that overweight and mild obesity may reduce mortality risk among moderately-to-severely frail older adults. These inconsistencies likely stem from limitations of traditional obesity metrics. Body mass index (BMI) cannot distinguish muscle from fat mass or reflect visceral fat distribution, while waist circumference fails to account for individual height differences in assessing abdominal adiposity.

Emerging obesity indicators offer improved assessment capabilities. Research by ZHAO Liancheng et al. found that waist-to-height ratio (WHtR) better identifies central obesity across different body types and correlates positively with cardiovascular disease and diabetes. Additionally, body roundness index (BRI) and Chinese visceral adiposity index (CVAI) effectively evaluate visceral fat accumulation. BRI demonstrates strong correlations with visceral fat area and metabolic status, while CVAI—incorporating waist circumference, BMI, lipid profiles, and sex—reflects visceral fat metabolic activity. Although visceral fat distribution shows clear associations with frailty, direct fat measurement remains impractical for large-scale community screening. This study therefore employs macro-level indicators (WHtR, BRI, CVAI) to assess obesity and explore their relationships with frailty, providing novel scientific evidence for health management and frailty prevention among older adults.

Methods

Study Population This study utilized China' s national basic public health service for elderly health management, conducted in community health centers across villages in Jingyuan County, Baiyin City, Gansu Province. From March to May 2023, we surveyed 1,429 rural residents aged 60+ years across six villages. Of these, 1,209 completed questionnaires (response rate 84.60%), with 1,153 participants included after applying exclusion criteria. Inclusion criteria were: (1) age $ $60 years; (2) completion of questionnaire, biochemical testing, and physical measurements; (3) local residence $ $5 years; (4) signed informed consent. Exclusion criteria included: (1) psychiatric history (e.g., schizophrenia) or communication disorders; (2) inability to undergo measurements due to long-term bedrest or disability; (3) unwillingness to cooperate. The study received approval from the Lanzhou University Ethics Committee (approval number: IRB21010301).

Data Collection General Information: Questionnaires collected demographic data including age, sex, ethnicity, marital status, education, family economic status, daily step count, smoking, alcohol consumption, tea drinking, and self-rated health. Chronic disease status was determined through self-report and on-site physician diagnosis, with multimorbidity defined as $ $2 chronic conditions and polypharmacy as $ $5 daily medications.

Physical Function and Sleep: Sleep quality was assessed using the Pittsburgh Sleep Quality Index (PSQI), with scores >7 indicating poor sleep. Upper and lower limb muscle strength were evaluated using the Short Physical Performance Battery (SPPB) and grip strength, where higher scores indicate better function.

Biochemical Measures: Fasting venous blood samples ($ $8 hours) were collected by professional physicians from Jingyuan County Traditional Chinese Medicine Hospital. Triglycerides (TG), total cholesterol (TC), high-density lipoprotein cholesterol (HDL-C), and low-density lipoprotein cholesterol (LDL-C) were measured using an automated biochemical analyzer (Beckman AU680).

Frailty Assessment Frailty was evaluated using the FRAIL scale, comprising five items: fatigue, endurance reduction, decreased mobility, $ $5 chronic diseases (e.g., hypertension, diabetes, cardiovascular disease, stroke, cancer, heart failure, asthma, arthritis, chronic lung disease, kidney disease, angina), and weight loss. Each positive item scores 1 point: 0=robust, 1-2=pre-frail, 3-5=frail. For this analysis, robust and pre-frail categories were combined as "non-frail."

Obesity Indicators Height and weight were measured using a standardized stadiometer (LK-200). Waist and hip circumferences were measured using a non-elastic tape with 1mm precision. Weight was recorded to 0.01 kg; height, waist, and hip circumferences to 0.01 cm. Measurements were categorized using Chinese standards: central obesity defined as waist circumference $ $90 cm (men) or $ $85 cm (women); BMI categories as underweight (< 18.50 kg/m^{2}), normal (18.50 – 23.99 kg/m^{2}), overweight (24.00–27.99 kg/m^{2}), mild obesity (28.00 – 32.49 kg/m^{2}), and to – severe obesity (32.50 kg/m^{2}$). WHR, WHtR, BRI, and CVAI were grouped by gender- and age-specific quartiles.

Calculation formulas: - BMI = weight (kg) / height (m)^2 - WHR = waist circumference (cm) / hip circumference (cm) - WHtR = waist circumference (cm) / height (cm) - BRI = 364.2 - 365.5×{1 - [waist (cm)/2π]^2 / [0.5×height (cm)]^2}^½ - Male CVAI = -267.93 + 0.68×age (years) + 0.03×BMI (kg/m^2) + 4.00×waist (cm) + 22.00×$\log_{10}$TG (mmol/L) - 16.32×HDL-C (mmol/L) - Female CVAI = -187.32 + 1.71×age (years) + 4.23×BMI (kg/m^2) + 1.12×waist (cm) + 39.76×$\log_{10}$TG (mmol/L) - 11.66×HDL-C (mmol/L)

Quartile groupings: - WHR (Q1: $ $0.86, Q2: 0.87-0.90, Q3: 0.91-0.94, Q4: >0.94) - WHtR (Q1: $ $0.51, Q2: 0.52-0.55, Q3: 0.56-0.59, Q4: >0.59) - BRI

(Q1: $ $3.49, Q2: 3.50-4.34, Q3: 4.35-5.30, Q4: >5.30) - CVAI (Q1: $ $99.11, Q2: 99.12-124.60, Q3: 124.61-146.35, Q4: >146.35)

Statistical Analysis Data were analyzed using SPSS 27.0 and R 4.3.1. Normally distributed continuous variables were expressed as mean±SD and compared between groups using independent t-tests. Categorical data were described using frequencies and percentages, with between-group comparisons using ^{2} tests. Multivariate logistic regression and restricted cubic splines (RCS) examined associations and dose-response relationships between obesity indicators and frailty, with trend tests and model adjustments. Three models were constructed: Model 1 unadjusted; Model 2 adjusted for age and sex; Model 3 adjusted for age, sex, ethnicity, marital status, education, family economic status, smoking, alcohol consumption, tea drinking, daily steps, multimorbidity, polypharmacy, falls, self-rated health, PSQI ($ $7 vs. >7), SPPB score, and grip strength. ROC curves were plotted to compare area under the curve (AUC) values. Gender- and age-stratified analyses were performed using sex- and age-specific quartiles. Two-sided P<0.05 indicated statistical significance.

Results

Participant Characteristics The final sample included 1,153 adults aged $ $60 years (474 men [41.11±$4.76 years). Based on FRAIL scale assessments, 226 participants were frail and 927 non-frail, yielding a frailty prevalence of 19.60%. Significant differences between frail and non-frail groups were observed for age, sex, marital status, education, family economic status, daily steps, smoking, tea consumption, self-rated health, multimorbidity, polypharmacy, PSQI, falls, grip strength, SPPB score, height, waist circumference, central obesity, BMI, WHR, WHtR, BRI, and CVAI (all P<0.05). No significant differences were found for ethnicity, alcohol consumption, weight, thigh circumference, calf circumference, or hip circumference .

Multivariate Logistic Regression Analysis Using frailty status as the dependent variable and obesity indicators (central obesity, BMI, WHR, WHtR, BRI, CVAI) as independent variables, multivariate logistic regression analysis (see variable coding in) revealed that after adjustment, central obesity, moderate-to-severe obesity (vs. normal BMI), Q3 and Q4 WHR, and Q4 WHtR, BRI, and CVAI (all vs. Q1) were significant risk factors for frailty (P<0.05). Frailty risk increased progressively with higher levels of waist circumference, BMI, WHR, WHtR, BRI, and CVAI (P-trend<0.05) .

Stratified Analysis by Sex and Age Gender- and age-stratified multivariate logistic regression (adjusted as in Model 3) showed that among men, central obesity and Q4 WHR, WHtR, BRI, and CVAI were risk factors (all vs. Q1, P<0.05), with increasing frailty risk across higher levels of waist circumference, WHR, WHtR, BRI, and CVAI (P-trend<0.05). Among women, central obesity,

mild obesity, moderate-to-severe obesity (vs. normal BMI), and Q4 WHtR and CVAI were risk factors (P<0.05), with increasing risk across higher levels of waist circumference, BMI, WHR, WHtR, and CVAI (P-trend<0.05). For participants aged $ $70 years, central obesity, overweight, mild obesity, moderate-to-severe obesity, and Q3-Q4 WHR, WHtR, BRI, and CVAI were risk factors (P<0.05), with significant upward trends for all indicators (P-trend<0.05) .

Dose-Response Relationships RCS analysis demonstrated linear positive associations between waist circumference, BMI, WHtR, BRI, CVAI and frailty risk (P-linear<0.05) [Figure 1: see original paper].

ROC Curve Analysis ROC analysis showed that waist circumference, BMI, WHR, WHtR, BRI, and CVAI all predicted frailty risk (all P<0.05) with AUCs of 0.557 (95%CI=0.515-0.598), 0.570 (95%CI=0.528-0.612), 0.558 (95%CI=0.515-0.600), 0.610 (95%CI=0.568-0.652), 0.610 (95%CI=0.568-0.652), and 0.586 (95%CI=0.546-0.626), respectively. WHtR, BRI, and CVAI showed significantly better predictive ability than waist circumference (Z=-5.443, P<0.001; Z=-5.443, P<0.001; Z=-2.595, P=0.009), while WHtR and BRI outperformed BMI (Z=-2.885, P=0.004; Z=-2.884, P=0.004) , [Figure 2: see original paper].

Discussion

Consistent with previous research, our findings confirm obesity as a risk factor for frailty. Obesity correlates with 21 disease categories, and more severe obesity increases chronic disease risk, which in turn associates with frailty. Studies show BMI is negatively associated with lower extremity function—a hallmark of frailty. However, some research suggests overweight and mild obesity may reduce mortality in moderately-to-severely frail elders, likely because BMI cannot differentiate fat distribution or muscle mass, complicating its relationship with health outcomes in aging.

Our study demonstrates that WHtR, BRI, and CVAI exhibit superior predictive value for frailty compared to traditional indicators. Korean research indicates WHtR mediates the BMI-frailty association, with longitudinal studies confirming WHtR as a stronger predictor of central obesity and frailty than waist circumference alone. BRI constructs an elliptical body model to assess visceral adiposity, showing stronger associations with metabolically unhealthy normal weight phenotypes that increase frailty risk. CVAI, developed specifically for Chinese populations using anthropometric and physiological parameters (BMI, waist circumference, TG, HDL-C), effectively reflects visceral fat metabolic activity. Visceral fat accumulation correlates with adipose tissue dysfunction, promoting insulin resistance and chronic inflammation—key pathophysiological mechanisms of frailty. Insulin resistance may increase muscle degradation via growth differentiation factor-8, while chronic low-grade inflammation, exacerbated by visceral fat, elevates IL-6, IL-18, and TNF-α levels, all associated with

poor physical function and frailty.

Significant associations between obesity indicators and frailty were primarily observed among participants aged $ $70 years. This likely reflects age-related sarcopenia and visceral fat accumulation, which increase free fatty acids and insulin resistance while promoting muscle atrophy through inflammatory pathways, collectively accelerating functional decline and frailty progression.

Weight reduction in obese older adults decreases chronic disease risk, but inappropriate approaches may reduce muscle mass and strength, increasing frailty risk. A randomized controlled trial in adults aged $ $65 years demonstrated that combined diet and exercise interventions effectively reduced weight while improving physical function. For frail obese elders, balanced nutrition and appropriate physical activity are essential to preserve muscle mass during weight loss.

Our study' s strengths include examining multiple obesity indicators and providing evidence from low-income rural Northwest China. Limitations include the cross-sectional design limiting causal inference, focus on rural elders restricting generalizability, lack of direct muscle mass adjustment (though grip strength and SPPB were included), and reliance on self-reported covariates potentially introducing recall bias.

Conclusion

Among rural adults aged $ $60 years in Northwest China, obesity—particularly central obesity—represents a significant frailty risk factor. Waist circumference, BMI, WHR, WHtR, BRI, and CVAI all correlate positively with frailty risk. WHtR and BRI demonstrate superior predictive performance compared to traditional metrics, offering valuable tools for early risk identification in primary care settings and informing targeted interventions. These findings provide important evidence for promoting healthy aging in resource-limited regions.

Author Contributions

ZHANG Zhiwei: data collection, statistical analysis, manuscript drafting. HE Panpan and YANG Qianwen: data collection and organization. JIN Xueyi, MAO Xueqian, and HU Ying: data collection. JING Lipeng: study supervision, quality control, funding acquisition.

Conflict of Interest Statement: The authors declare no conflicts of interest.

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References

[1] Chinese Medical Association Geriatrics Branch, YANG Yunmei, TUO Xiping, et al. Chinese expert consensus on frailty prevention in older adults (2022)[J].

Chinese Journal of Critical Care Medicine (Electronic Edition), 2022, 15(2): 89-97. DOI: 10.3877/cma.j.issn.1674-6880.2022.02.001.

[2] HOOGENDIJK E O, AFILALO J, ENSRUD K E, et al. Frailty: implications for clinical practice and public health[J]. Lancet, 2019, 394(10206): 1365-1375. DOI: 10.1016/S0140-6736(19)S383597.

[3] YIN Jiahui, ZENG Yanbing, ZHOU Zi, et al. Analysis of frailty status and influencing factors among Chinese older adults[J]. Chinese Journal of Epidemiology, 2018, 39(9): 1244-1248. DOI: 10.3760/cma.j.issn.0254-6450.2018.09.019.

[4] HOU Shajie, DING Yao, GUO Xiaolan, et al. Meta-analysis of frailty prevalence and influencing factors among Chinese community-dwelling older adults[J]. New Medicine, 2024, 34(3): 301-310.

[5] LUO Jiakun, MA Yufei, LIU Ruihan, et al. Epidemiological study of frailty distribution in older adults[J]. Chinese Journal of Medical Frontiers (Electronic Edition), 2023, 15(5): 6-11.

[6] YUAN L L, CHANG M L, WANG J. Abdominal obesity, body mass index and the risk of frailty in community-dwelling older adults: a systematic review and meta-analysis[J]. Age Ageing, 2021, 50(4): 1118-1128. DOI: 10.1093/ageing/afab039.

[7] AFONSO C, SOUSA-SANTOS A R, SANTOS A, et al. Frailty status is related to general and abdominal obesity in older adults[J]. Nutr Res, 2021, 85: 21-30. DOI: 10.1016/j.nutres.2020.10.009.

[8] JAYANAMA K, THEOU O, GODIN J, et al. Relationship of body mass index with frailty and all-cause mortality among middle-aged and older adults[J]. BMC Med, 2022, 20(1): 404. DOI: 10.1186/s12916-022-02596-7.

[9] The Lancet Diabetes Endocrinology. Redefining obesity: advancing care for better lives[J]. Lancet Diabetes Endocrinol, 2025, 13(2): 75. DOI: 10.1016/S2213-8587(25)00004-X.

[10] ZHAO Liancheng, PENG Yaguang, LI Ying, et al. Comparison of waist circumference and waist-to-height ratio in predicting central obesity[J]. Chinese Journal of Epidemiology, 2013, 34(2): 120-124. DOI: 10.3760/cma.j.issn.0254-6450.2013.02.0003.

[11] FENG Q, BEŠEVIĆ J, CONROY M, et al. Waist-to-height ratio and body fat percentage as risk factors for ischemic cardiovascular disease: a prospective cohort study from UK Biobank[J]. Am J Clin Nutr, 2024, 119(6): 1386-1396. DOI: 10.1016/j.ajcnut.2024.03.018.

[12] SHENG G T, QIU J J, KUANG M B, et al. Assessing temporal differences of baseline body mass index, waist circumference, and waist-height ratio in predicting future diabetes[J]. Front Endocrinol (Lausanne), 2023, 13: 1020253. DOI: 10.3389/fendo.2022.1020253.

[13] CHEN Y J, WANG C C, SUN Q N, et al. Comparison of novel and traditional anthropometric indices in Eastern-China adults: which is the best indicator of the metabolically obese normal weight phenotype?[J]. BMC Public Health, 2024, 24(1): 2192. DOI: 10.1186/s12889-024-19638-9.

[14] FERREIRA J R S, LIBARDI M C, DO PRADO C B, et al. Predicting metabolic syndrome by lipid accumulation product, visceral adiposity index and body roundness index in Brazilian rural workers[J]. BMC Public Health, 2025, 25(1): 544. DOI: 10.1186/s12889-025-21624-8.

[15] YANG Y H, LI S X, REN Q, et al. The interaction between triglyceride-glucose index and visceral adiposity in cardiovascular disease risk: findings from a nationwide Chinese cohort[J]. Cardiovasc Diabetol, 2024, 23(1): 427. DOI: 10.1186/s12933-024-02518-2.

[16] LI B X, LI Y, ZHANG Y X, et al. Visceral fat obesity correlates with frailty in middle-aged and older adults[J]. Diabetes Metab Syndr Obes, 2022, 15: 2877-2884. DOI: 10.2147/DMSO.S383597.

[17] SKOU S T, MAIR F S, FORTIN M, et al. Multimorbidity[J]. Nat Rev Dis Primers, 2022, 8: 48. DOI: 10.1038/s41572-022-00392-5.

[18] CI Liya, YANG Changchun, ZHENG Pengyuan, et al. Chinese expert consensus on medication safety management for frail older adults in integrated care facilities (2022 edition)[J]. Chinese Journal of Health Care Medicine, 2022, 24(5): 355-362. DOI: 10.3969/j.issn.1007-5410.2022.05.002.

[19] LI J, YAO Y S, DONG Q, et al. Characterization and factors associated with sleep quality among rural elderly in China[J]. Arch Gerontol Geriatr, 2013, 56(1): 237-243. DOI: 10.1016/j.archger.2012.08.002.

[20] ABELLAN VAN KAN G, ROLLAND Y M, MORLEY J E, et al. Frailty: toward a clinical definition[J]. J Am Med Dir Assoc, 2008, 9(2): 71-72. DOI: 10.1016/j.jamda.2007.11.005.

[21] National Health Commission of the People' s Republic of China Medical Administration. Chinese guidelines for the diagnosis and treatment of obesity (2024 edition)[J]. Peking Union Medical College Hospital Journal, 2025, 16(1): 90-108. DOI: 10.12290/xhyxzz.2024-0918.

[22] KIVIMÄKI M, STRANDBERG T, PENTTI J, et al. Body-mass index and risk of obesity-related complex multimorbidity: an observational multicohort study[J]. Lancet Diabetes Endocrinol, 2022, 10(4): 253-263. DOI: 10.1016/S2213-8587(22)00033-X.

[23] LIN Yang, WANG Fang, WANG Han, et al. Meta-analysis of frailty prevalence among older adults with multimorbidity[J]. Chinese General Practice, 2023, 26(25): 3185-3193. DOI: 10.12114/j.issn.1007-9572.2022.0521.

[24] BJÖRKMAN M P, JYVÄKORPI S K, STRANDBERG T E, et al. The associations of body mass index, bioimpedance spectroscopy-based calf intra-

cellular resistance, single-frequency bioimpedance analysis and physical performance of older people[J]. Aging Clin Exp Res, 2020, 32(6): 1077-1083. DOI: 10.1007/s40520-019-01328-8.

[25] WANG S Y, REN J. Obesity paradox in aging: from prevalence to pathophysiology[J]. Prog Cardiovasc Dis, 2018, 61(2): 182-189.

[26] GAO Rong, SU Ye, CHEN Peiyan, et al. Research progress on appropriate body mass index for older adults[J]. Chinese Journal of Geriatrics, 2016, 35(9): 1022-1026. DOI: 10.3760/cma.j.issn.0254-9026.2016.09.025.

[27] KIM M, LEE Y, KIM E Y, et al. Mediating effect of waist:height ratio on the association between BMI and frailty: the Korean frailty and aging cohort study[J]. Br J Nutr, 2020, 124(5): 513-520. DOI: 10.1017/S0007114519002058.

[28] ESLAMI M, FAKHRZADEH H, POURGHAZI F, et al. The association between frailty and body composition among the elderly: Birjand Longitudinal Aging Study (BLAS)[J]. J Diabetes Metab Disord, 2023, 23(1): 967-976. DOI: 10.1007/s40200-023-01431-5.

[29] PARTEZANI RODRIGUES R A, SILVA FHON J R, ROJAS HUAYTA V M, et al. Frailty syndrome and anthropometric measurements in the elderly living at home[J]. J Aging Res & Lifestyle, 2017: 1-7. DOI: 10.14283/jarcp.2017.15.

[30] HE D, QIU Y W, YAN M S, et al. Associations of metabolic heterogeneity of obesity with frailty progression: Results from two prospective cohorts[J]. J Cachexia Sarcopenia Muscle, 2023, 14(1): 632-641. DOI: 10.1002/jcsm.13169.

[31] XIA M F, CHEN Y, LIN H D, et al. A indicator of visceral adipose dysfunction to evaluate metabolic health in adult Chinese[J]. Sci Rep, 2016, 6: 38214. DOI: 10.1038/srep38214.

[32] NEELAND I J, LIM S, TCHERNOF A, et al. Metabolic syndrome[J]. Nat Rev Dis Primers, 2024, 10: 77. DOI: 10.1038/s41572-024-00563-5.

[33] KIM D H, ROCKWOOD K. Frailty in Older Adults[J]. N Engl J Med, 2024, 391(6): 538-548. DOI: 10.1056/NEJMra2301292.

[34] EL ASSAR M, RODRÍGUEZ-SÁNCHEZ I, ÁLVAREZ-BUSTOS A, et al. Biomarkers of frailty[J]. Mol Aspects Med, 2024, 97: 101271. DOI: 10.1016/j.mam.2024.101271.

[35] FERRUCCI L, FABBRI E. Inflammageing: chronic inflammation in ageing, cardiovascular disease, and frailty[J]. Nat Rev Cardiol, 2018, 15(9): 505-522. DOI: 10.1038/s41569-018-0051-2.

[36] BEKTAŞ A, SCHURMAN S H, SEN R, et al. Aging, inflammation and the environment[J]. Exp Gerontol, 2018, 105: 10-18. DOI: 10.1016/j.exger.2017.12.015.

[37] MA L N, SHA G M, ZHANG Y X, et al. Elevated serum IL-6 and adiponectin levels are associated with frailty and physical function in

Chinese older adults[J]. Clin Interv Aging, 2018, 13: 2013-2020. DOI: 10.2147/CIA.S180934.

[38] FRAYLING T M, RAFIQ S, MURRAY A, et al. An interleukin-18 polymorphism is associated with reduced serum concentrations and better physical functioning in older people[J]. J Gerontol A Biol Sci Med Sci, 2007, 62(1): 73-78. DOI: 10.1093/gerona/62.1.73.

[39] PICCA A, COELHO-JUNIOR H J, CALVANI R, et al. Biomarkers shared by frailty and sarcopenia in older adults: a systematic review and meta-analysis[J]. Ageing Res Rev, 2022, 73: 101530. DOI: 10.1016/j.arr.2021.101530.

[40] KELLER K, ENGELHARDT M. Strength and muscle mass loss with aging process. Age and strength loss[J]. Muscles Ligaments Tendons J, 2014, 3(4): 346-350.

[41] PALMER A K, JENSEN M D. Metabolic changes in aging humans: current evidence and therapeutic strategies[J]. J Clin Invest, 2022, 132(16): e158451. DOI: 10.1172/JCI158451.

[42] KOGA Y, FUJITA M, HARADA K, et al. Increased fat accumulation may be associated with severe muscle wasting in critically ill patients: a prospective observational study[J]. Sci Rep, 2025, 15: 11460. DOI: 10.1038/s41598-025-96171-8.

[43] WU H Z, BALLANTYNE C M. Skeletal muscle inflammation and insulin resistance in obesity[J]. J Clin Invest, 2017, 127(1): 43-54. DOI: 10.1172/JCI88880.

[44] DIMILIA P R, MITTMAN A C, BATSIS J A. Benefit-to-risk balance of weight loss interventions in older adults with obesity[J]. Curr Diab Rep, 2019, 19(11): 114. DOI: 10.1007/s11892-019-1248-6.

[45] VILLAREAL D T, CHODE S, PARIMI N, et al. Weight loss, exercise, or both and physical function in obese older adults[J]. N Engl J Med, 2011, 364(13): 1218-1229. DOI: 10.1056/NEJMoa1008234.

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