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RESEARCH ARTICLE

# The association between frailty and body composition among the elderly: Birjand Longitudinal Aging Study (BLAS)

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## Abstract

**Background** This study aims to assess the possible relationship between frailty and anthropometric indices in older adults using data from the first phase of the Birjand Longitudinal Aging Study (BLAS).

**Methods** In this cross-sectional study, we assessed the association between frailty (Frailty index (FI) and Fried frailty phenotype) and body composition indices in 1364 participants aged ≥ 60 years (September 2018 to April 2019). Analysis was conducted using one-way ANOVA and ordinal logistic regression.

**Results** Participants were categorized as frail (n = 164), non-frail (n = 415), and pre-frail (n = 785) based on FI. A significant positive association was observed between the frailty and body mass index (BMI) (OR: 1.04, 95% CI:1.01- 1.07), waist circumference (WC) (OR: 1.02, 95% CI: 1.01- 1.03), waist-to-hip ratio (WHR) (OR: 2.36, 95% CI 1.05- 5.27) and waist-to-height ratio (WHtR) (OR: 1.27, 95%CI: 1.09- 1.47). Body shape index, body roundness index, and body adiposity index showed no significant association with frailty. Moreover, a BMI greater than 29 kg/m$^2$ increased the odds of frailty and prefrailty by 79% (OR = 1.79, 95%CI = 1.30- 2.46, P < 0.001).

**Conclusion** Results of this study showed that the risk of frailty increases as BMI and abdominal obesity indices increase. Therefore, BMI and abdominal obesity indices (WC, WHR, and WHtR) could serve as suitable tools for evaluating frailty in the elderly. However, additional studies are needed to evaluate the utility of the newly developed anthropometric indices in older adults.

**Keywords** Aging · Body composition · Elderly · Frailty syndrome · Obesity

## Background

Over the past century, life expectancy has witnessed significant growth worldwide, owing to advancements in public health [1]. This notable demographic shift has contributed to a rise in the population of older adults across developed, developing, and low-income countries [2]. The World Population Report projects that the global population of individuals aged 60 years and older will reach 2 billion by the year 2050 [1]. According to a meta-analysis of population-level studies encompassing 62 countries, the prevalence of frailty was found to be 24% and pre-frailty

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49%, as determined by the deficit accumulation model [3]. Also, Different regions in Iran have reported a varied prevalence of frailty, ranging from 14.3% to 46.7% [4–8].

Frailty is a clinical condition that is defined as a decline in an individual's physical and mental capacities (Intrinsic Capacity) and increased vulnerability to cope with everyday or acute stressors which leads to adverse outcomes [9, 10]. Frailty syndrome depends on several factors including genetic, cumulative environmental impact, nutrition, lifestyle choices, physiological changes in aging, psychological factors, chronic disease, etc. [11–14].

The two most commonly used measurement tools for frailty are the Fried phenotype and The Frailty Index. The Fried phenotype [15] consists of five components including unintentional weight loss, self-reported exhaustion, weakness, slow walking speed, and low physical activity. The Frailty Index is based on the accumulative health deficits model. In contrast with the phenotype model, The Frailty Index considers the cognitive condition of the older adult, and is also more sensitive and multidimensional to adverse health outcomes [5, 16, 17].

Various pathological conditions are accompanied by frailty such as weight loss, sarcopenia, anorexia, and low protein intake [18, 19]. As well as low body weight, obese older people are at risk of frailty [12]. Several articles have reported on the relationship between general and central obesity and frailty in the older population [20–22]. They have shown a positive association between abdominal obesity and increased risk of frailty. Moreover, findings indicated a direct association between the simultaneous presence of general and abdominal obesity with frailty and pre-frailty. The study underscored the importance of evaluating Body Mass Index (BMI) and Waist Circumference (WC) together in older adults [22]. Anthropometric indices including weight, BMI, WC, Waist-to-Hip Ratio (WHR), Hip Circumference (HC), and Waist-to-Height Ratio (WHtR) constitute essential components in the assessment of body composition. Recently, new anthropometric indices have been developed to more accurately reflect the composition of body fat and visceral fat by combining traditional indices such as WC, HP, and BMI.

Body Roundness Index (BRI) is an obesity-related index that represents body shape and some studies have demonstrated that BRI is associated with diabetes mellitus, and cardiovascular diseases [23–26]. A Body Shape Index (ABSI) is another novel anthropometric tool, based on BMI, WC, and height. ABSI was developed in 2012 by Krakauer et al. and was offered as a risk factor for premature death [27]. Moreover, the Body Adiposity Index (BAI) is suggested as a simple index to reflect on obesity, with a high correlation with body fat measured by Dual-energy X-ray Absorption (DXA) [28].

Due to demographic growth, the concept of "Frailty Syndrome" has been the center of attention by the public health policy-makers. Frailty has a dynamic nature [29], thus, knowing the associated factors of frailty can make it possible to preserve or improve physical and cognitive impairment, to prevent disability, dependency, hospitalization, and death [9]. To our knowledge, literature regarding the association between novel anthropometric indices and both frailty index and frailty phenotype is absent. We aimed to investigate the existence and extent of the relationship between frailty and various anthropometric indices in older adults, using data from the Birjand Longitudinal Aging Study (BLAS).

## Methods

### Design and Population

This cross-sectional study was conducted using data from the enrolment phase of the Birjand longitudinal aging study (BLAS) (total sample size = 1420) which was conducted from September 2018 to April 2019 in Birjand, Iran. BLAS is an ongoing prospective cohort study and the participants of this research are community-dwelling older adults over 60 years of age, residents of Birjand (excluding the rural areas). details of the study method have already been published [30]. Anthropometric indices, dietary habits, sociodemographic characteristics, and history of chronic illnesses and medications were obtained through pretested valid questionnaires, which were completed by trained interviewers. This study was approved by the research ethics committee of the Endocrinology Metabolism Research Institute of Tehran University of Medical Sciences (code: IR.TUMS.EMRI.REC.1396.00158) and written informed consent was obtained from all participants before participation.

### Exclusion criteria

Exclusion criteria were as follows: anatomical defects or decreased strength that could affect performance on tests, being a chair or bed-ridden even if transiently, advanced Parkinson's disease and missing anthropometric data. Out of 1420 BLAS participants, 56 elderly were excluded from the current research and analysis was done on 1364 participants.

### Anthropometric Assessment

Weight was measured with the least amount of clothing by calibrated SECA digital scale at the nearest 0.1 kg (SECA, Germany). Height was measured with participants standing straight, at the nearest 0.1 cm (SECA, Germany). Body mass index (BMI) was calculated as weight (kg) divided by the square of height ($m^2$). Waist circumference (WC) was

recorded to the nearest 0.5 cm using non-stretch tape placed midway between the iliac crest and lowest rib while participants were in the standing position. Hip circumference (HC) was measured at the distance around the largest part of the hips (the widest part of the buttocks). Waist-to-height ratio (WHtR) and waist-to-hip ratio (WHR) were measured by dividing WC into height and hip circumference, respectively.

Body roundness index (BRI), body adiposity index (BAI), and body shape index (ABSI) were calculated using the following formulas [31, 32]:

$$\mathrm{ABSI} = \mathrm{WC}/[(\mathrm{BMI})^{(2/3)} \times (\mathrm{height})^{(1/2)}]$$

$$\mathrm{BRI} = 365.2 - 365.5 \times \sqrt{(1 - (((\mathrm{wc}/2\pi)2)/[(0.5 \times \mathrm{height})]^2))}$$

$$\mathrm{BAI} = (\mathrm{hip\ circumference}/\mathrm{height}^{1.5}) - 18$$

As the values were too small, the Z-score of WHtR and ABSI was used for analysis ((value-mean)/SD). Based on a recent meta-analysis, BMI was categorized as a risk factor($\leq 24$ and $\geq 29$) or normal ($24 < \mathrm{BMI} < 29$), according to the cut-off points determined for the elderly population [33].

### Assessment of frailty

A frailty index counts deficits in health. Restricted activity, disability in Activities of Daily Living (ADL), impairments in general cognition (including Mini–mental state examination (MMSE) and Six-item Cognitive Impairment Test (6-CIT)), physical performance (including impaired grip strength, impaired walking, and low skeletal muscle index), co-morbidity, self-rated depression/mood disorder were evaluated as health deficits. For each individual, The Frailty Index (FI) was calculated by summing all health deficits and dividing it by the total number of health deficits. We classified the continuous frailty index into non-frail ($\mathrm{FI} < 0.20$), pre-frail ($0.20 \leq \mathrm{FI} < 0.45$), and frail ($\mathrm{FI} \geq 0.45$) [34].

The frailty phenotype is based on five criteria testing the presence or absence of signs and symptoms of frailty (including involuntary weight loss, exhaustion, slow gait speed, poor handgrip strength, and sedentary behavior). The number of criteria is categorized into a 3-level variable depicting robustness (none of the criteria), pre-frailty (one or two criteria), and frailty (three or more criteria) [15].

### Other variables

Socio-demographic information was obtained including age, sex, smoking status, marital status, education status, physical activity, and chronic disorders (cardiovascular, hypertension, hyperlipidemia, osteoporosis, diabetes mellitus, stroke, seizure, arthritis, heart failure, cancer, gout, thyroid disorders, and surgical history). The Patient Health Questionnaire-9 (PHQ-9) was used to assess depression [35]. Polypharmacy (using 3 drugs or more) and multimorbidity (having more than 3 diseases) were assessed in the participants. The forward selection method was used to choose confounders and covariates [36]. Variables including age, sex, duration of education, physical activity, job, depression, and smoking remained in the model as covariates.

### Statistical Analysis

Continuous variables were presented as mean (standard deviation (SD)), and categorical variables were presented as frequency (%). All results were reported separately for frail, pre-frail, and non-frail individuals. The one-way ANOVA was used to compare demographic and anthropometric indices between the three groups of frailty. For the categorical variables, the difference between the two groups was assessed by Chi-square or Fisher's exact test. The association of body composition indices and frailty was assessed by ordinal logistic regression and results were expressed as Odds Ratio (OR) (95% Confidence Interval (CI)). The BLAS data was initially provided in SPSS format, we proceeded to clean and analyze the basic data (general participant characteristics) in SPSS. Subsequently, the main analyses were carried out in STATA version 14.2 (StataCorp. 2015. Stata Statistical Software: Release 14. College Station, TX: StataCorp LP.), and a P-value $\leq 0.05$ was considered statistically significant.

## Results

Table 1 summarizes the anthropometric and demographic characteristics of the 1364 participants. The study sample was comprised of 707 women (51.8%) and 657 men (48.2%) with a mean age of $69.77 \pm 7.66$ years old. Few participants had a university education (17.7% of men and 12.7% of women). Most participants were married (81.3%) and illiterate (45.7%), and they were mostly housewives or freelancers (55.2%). Only a minor group of all participants were smokers (7%) and had low physical activity (13.2%). Polypharmacy was common among the studied population (65%) and 55.1% of them were suffering from multiple chronic diseases.

Comparing the three groups of frail ($n = 164$), non-frail ($n = 415$), and pre-frail ($n = 785$) participants based on FI, it was observed that all the socio-demographic characteristics of the participants were significantly different ($P \leq 0.05$), except for multimorbidity ($P = 0.09$). The score of the PHQ-9 questionnaire had an ascending trend in non-frail (mean (SD) = 1.92 (2.66)), pre-frail (6.12 (4.85)), and frail (10.55 (5.48)) participants ($P < 0.001$). Regarding the body composition indices, weight, BMI,

**Table 1** General characteristics of study participants

| Variables | | Overall (n = 1364) | Frailty status | | | P-value |
|---|---|---|---|---|---|---|
| | | | Non-frail (n = 415) | Pre-frail (n = 785) | Frail (n = 164) | |
| Age (years) | | 69.77 (7.66) | 67.65 (6.48) | 69.79 (7.49) | 75.07 (8.65) | < 0.001 |
| Height (cm) | | 157.46 (10.28) | 163.00 (8.94) | 155.99 (9.81) | 151.23 (9.90) | < 0.001 |
| Weight (kg) | | 65.41 (13.38) | 67.98 (12.10) | 64.50 (13.54) | 63.29 (14.78) | < 0.001 |
| BMI | | 26.43 (5.33) | 25.74 (4.80) | 26.51 (5.13) | 27.81 (7.05) | < 0.001 |
| WC (cm) | | 95.30 (11.89) | 93.76 (11.00) | 95.70 (12.08) | 97.28 (12.74) | 0.002 |
| HC (cm) | | 99.80 (10.94) | 99.58 (10.86) | 99.85 (10.94) | 100.13 (11.22) | 0.85 |
| WHR | | 0.97 (0.16) | 0.95 (0.15) | 0.97 (0.16) | 0.98 (0.16) | 0.08 |
| WHtR | | 0.61 (0.09) | 0.58 (0.07) | 0.62 (0.09) | 0.64 (0.09) | < 0.001 |
| BRI | | 4.66 (1.71) | 4.68 (1.92) | 4.65 (1.61) | 4.60 (1.66) | 0.88 |
| ABSI | | 0.09 (0.01) | 0.08 (0.00) | 0.09 (0.01) | 0.09 (0.01) | < 0.001 |
| BAI | | 32.94 (7.85) | 30.28 (6.95) | 33.64 (7.70) | 36.32 (8.65) | < 0.001 |
| FI | | 0.28 (0.13) | 0.14 (0.04) | 0.31 (0.07) | 0.52 (0.07) | < 0.001 |
| PHQ-9 | | 5.37 (5.14) | 1.92 (2.66) | 6.12 (4.85) | 10.55 (5.48) | < 0.001 |
| Physical activity | inactive | 510 (37.4%) | 62 (14.9%) | 321 (49.9%) | 127 (77.4%) | < 0.001 |
| | Low | 180 (13.2%) | 42 (10.1%) | 120 (15.3%) | 18 (11.0%) | |
| | Moderate | 674 (49.6%) | 311 (74.9%) | 344 (43.8%) | 19 (11.6%) | |
| Sex | Female | 707 (51.8%) | 100 (24.1%) | 472 (60.1%) | 135 (82.3%) | < 0.001 |
| | Male | 657 (48.2%) | 315 (75.9%) | 313 (39.9%) | 29 (17.7%) | |
| Marital status | Single, divorced or widowed | 255 (18.7%) | 28 (6.7%) | 164 (20.9%) | 63 (38.4%) | < 0.001 |
| | Married | 1109 (81.3%) | 387 (93.3%) | 621 (79.1%) | 101 (61.6%) | |
| Education | 0 | 623 (45.7%) | 86 (20.7%) | 412 (52.5%) | 125 (76.2%) | < 0.001 |
| | 1–8 years | 470 (34.5%) | 174 (41.9%) | 263 (33.5%) | 33 (20.1%) | |
| | Over 9 years | 271 (19.9%) | 155 (37.3%) | 110 (14.0%) | 6 (3.7%) | |
| Smoking status* | Yes | 96 (7.0%) | 46 (11.1%) | 48 (6.1%) | 2 (1.2%) | < 0.001 |
| | No | 1268 (93.0%) | 369 (88.9%) | 737 (93.9%) | 162 (98.8%) | |
| Job status* | Retired or unemployed | 566 (41.5%) | 274 (66.0%) | 273 (34.8%) | 19 (11.6%) | < 0.001 |
| | Housewife or freelancer | 753 (55.2%) | 127 (30.6%) | 485 (61.8%) | 27 (3.4%) | |
| | Farmer or employed | 45 (3.3%) | 14 (3.4%) | 27 (3.4%) | 4 (2.4%) | |
| Polypharmacy | Less than 3 drugs | 886 (65.0%) | 333 (80.2%) | 485 (61.8%) | 68 (41.5%) | < 0.001 |
| | 3 drugs or more | 478 (35.0%) | 82 (19.8%) | 300 (38.2%) | 96 (58.5%) | |
| Multimorbidity | Yes | 752 (55.1%) | 218 (52.5%) | 452 (57.6%) | 82 (50.0%) | 0.09 |
| | No | 612 (44.9%) | 197 (47.5%) | 333 (42.4%) | 82 (50.0%) | |

one-way ANOVA (mean (Standard Deviation)) or Chi-square test (n (%)), *: Fisher's exact test

BMI: Body Mass Index, WC: Waist Circumference, HC: Hip Circumference, WHR: Waist to Hip Ratio, WHtR: Waist to Height Ratio, BRI: Body roundness index, BAI: body adiposity index, ABSI: a body shape index, FI: Frailty Index, PHQ-9: Patient Health Questionnaire-9

WHtR, BAI, ABSI ($P < 0.001$), and WC ($P = 0.002$) were significantly different between the three groups, while WHR ($P = 0.08$), HC ($P = 0.85$), and BRI ($P = 0.88$) had no remarkable difference. Except for BRI and weight, all the anthropometric variables had a descending trend as the severity of frailty increased.

As shown in Table 2, a significant direct association between all body composition indices and FI was observed in the crude model ($P < 0.05$), except for BRI ($P > 0.05$). After adjustment for confounders, BMI, WC, WHR, and WHtR were still recognized as risk factors for frailty and pre-frailty, while the significance of the relationship disappeared regarding BAI and ABSI.

Regarding the frailty phenotype, BMI was the only index that was significantly related to frailty in both the crude and the adjusted models (OR = 0.97; 95%CI = 0.95- 0.99; $P = 0.02$). the association between BMI and frailty phenotype was inverse ($OR < 1.00$), while this association was direct when considering FI ($OR > 1.00$).

Considering the specific cut-off points of BMI among older adults, $24 \leq BMI \leq 29$ kg/m$^2$ was considered as the reference category. Analysis showed that both low

**Table 2** Association between frailty (3 categories) and body composition indices (continuous)

| Body Composition | | Frailty (3 categories) | | | | | |
|---|---|---|---|---|---|---|---|
| | | Frailty index | | | Frailty phenotype | | |
| | | OR | 95% CI | P-value | OR | 95% CI | P-value |
| BMI | Crude | 1.04 | 1.02; 1.06 | < 0.001 | 0.97 | 0.95; 0.99 | 0.02 |
| | Model 1 | 1.02 | 1.00; 1.05 | 0.02 | 0.97 | 0.95; 0.99 | 0.01 |
| | Model 2 | 1.02 | 1.00; 1.05 | 0.02 | 0.97 | 0.95; 0.99 | 0.01 |
| | Model 3 | 1.04 | 1.01; 1.07 | 0.002 | 0.97 | 0.95; 0.99 | 0.02 |
| WC | Crude | 1.01 | 1.01; 1.02 | < 0.001 | 0.99 | 0.98; 1.00 | 0.21 |
| | Model 1 | 1.01 | 1.01; 1.02 | 0.03 | 0.99 | 0.98; 1.00 | 0.16 |
| | Model 2 | 1.01 | 1.00; 1.02 | 0.02 | 0.99 | 0.98; 1.00 | 0.18 |
| | Model 3 | 1.02 | 1.01; 1.03 | 0.002 | 0.99 | 0.98; 1.00 | 0.21 |
| WHR | Crude | 2.13 | 1.10; 4.13 | 0.02 | 0.87 | 0.40; 1.89 | 0.73 |
| | Model 1 | 1.32 | 0.65; 2.70 | 0.44 | 0.84 | 0.38; 1.84 | 0.66 |
| | Model 2 | 1.66 | 0.78; 3.50 | 0.18 | 0.86 | 0.39; 1.89 | 0.71 |
| | Model 3 | 2.36 | 1.05; 5.27 | 0.04 | 0.89 | 0.40; 1.97 | 0.78 |
| WHtR (Z-score) | Crude | 1.67 | 1.50; 1.86 | < 0.001 | 0.92 | 0.82; 1.04 | 0.19 |
| | Model 1 | 1.21 | 1.06; 1.37 | 0.003 | 0.89 | 0.78; 1.03 | 0.12 |
| | Model 2 | 1.15 | 1.01; 1.32 | 0.03 | 0.89 | 0.78; 1.03 | 0.13 |
| | Model 3 | 1.27 | 1.09; 1.47 | 0.001 | 0.90 | 0.78; .04 | 0.14 |
| ABSI (Z-score) | Crude | 1.37 | 1.23; 1.53 | < 0.001 | 1.05 | 0.93; 1.19 | 0.40 |
| | Model 1 | 1.04 | 0.93; 1.16 | 0.49 | 1.06 | 0.94; 1.20 | 0.33 |
| | Model 2 | 1.00 | 0.89; 1.13 | 0.96 | 1.06 | 0.94; 1.20 | 0.37 |
| | Model 3 | 1.00 | 0.88; 1.14 | 0.98 | 1.05 | 0.93; 1.19 | 0.42 |
| BRI | Crude | 0.98 | 0.93; 1.05 | 0.64 | 1.04 | 0.97; 1.12 | 0.27 |
| | Model 1 | 1.02 | 0.95; 1.08 | 0.59 | 1.04 | 0.97; 1.11 | 0.28 |
| | Model 2 | 1.03 | 0.96; 1.10 | 0.42 | 1.04 | 0.97; 1.12 | 0.27 |
| | Model 3 | 1.00 | 0.93; 1.08 | 0.91 | 1.04 | 0.97; 1.12 | 0.28 |
| BAI | Crude | 1.07 | 1.05; 1.08 | < 0.001 | 0.99 | 0.98; 1.01 | 0.57 |
| | Model 1 | 1.02 | 1.00; 1.03 | 0.04 | 0.99 | 0.98; 1.01 | 0.59 |
| | Model 2 | 1.00 | 0.98; 1.02 | 0.92 | 0.99 | 0.98; 1.01 | 0.55 |
| | Model 3 | 1.00 | 0.99; 1.02 | 0.58 | 0.99 | 0.98; 1.01 | 0.52 |

Ordinal logistic regression, data represented as OR (95%CI)

Model 1: adjusted for age & sex

Model 2: adjusted for age, sex, education, physical activity

Model 3: adjusted for age, sex, education, physical activity, depression, job, smoking

OR: Odds Ratio, CI: confidence interval

(OR = 1.29; 95%CI = 1.01- 1.65; P = 0.04) and high BMI (OR = 1.98; 95%CI = 1.52- 2.57; P < 0.001) increased the odds of frailty and pre-frailty in the crude model (Table 3). The association was still significant in the adjusted models only for the group with BMI > 29 kg/$m^2$. In other words, BMI > 29 kg/$m^2$ increased the odds of frailty and prefrailty by 79% (OR = 1.79, 95%CI = 1.30-2.46, P < 0.001) while no significant relationship was observed for frailty phenotype and categories of BMI.

## Discussion

The current study was performed on 1364 older adults over 60 years old to evaluate the relationship between frailty and anthropometric indices, using data from the Birjand longitudinal aging study (BLAS). Overall, our study analysis illustrated a significant positive association between FI and BMI, WC, WHR and, WHtR in the final model,

**Table 3** Association between frailty (3 categories) and BMI categories

| frailty | | BMI | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 24 ≤ BMI ≤ 29 | BMI < 24 | | | BMI > 29 | | | |
| | | | OR | 95% CI | P-value | OR | 95% CI | P-value | P-trend |
| Frailty index | Crude | reference | 1.29 | 1.01; 1.65 | 0.04 | 1.98 | 1.52; 2.57 | < 0.001 | < 0.001 |
| | Model 1 | reference | 1.23 | 0.95; 1.60 | 0.12 | 1.57 | 1.18; 2.07 | 0.002 | |
| | Model 2 | reference | 1.21 | 0.91; 1.60 | 0.18 | 1.72 | 1.28; 2.32 | < 0.001 | |
| | Model 3 | reference | 1.00 | 0.74; 1.35 | 0.99 | 1.79 | 1.30; 2.46 | < 0.001 | |
| Frailty phenotype | Crude | reference | 1.00 | 0.75; 1.33 | 0.99 | 0.81 | 0.60; 1.10 | 0.18 | 0.21 |
| | Model 1 | reference | 1.03 | 0.77; 1.38 | 0.84 | 0.80 | 0.59; 1.08 | 0.15 | |
| | Model 2 | reference | 1.02 | 0.76; 1.36 | 0.90 | 0.80 | 0.59; 1.09 | 0.16 | |
| | Model 3 | reference | 0.99 | 0.74; 1.33 | 0.97 | 0.80 | 0.59; 1.09 | 0.15 | |

Ordinal logistic regression, data represented as OR (95%CI)

Model 1: adjusted for age & sex

Model 2: adjusted for age, sex, education, physical activity

Model 3: adjusted for age, sex, education, physical activity, depression, job, smoking

OR: Odds Ratio, CI: confidence interval, BMI: Body Mass Index

which was adjusted for age, sex, education, physical activity, depression, job and, smoking. On the other hand, only BMI was significantly associated with frailty phenotype as a protective factor (OR < 1).

The prevalence of frailty and pre-frailty were 12% and 57% in this study using FI, respectively. The prevalence of frailty is dependent on the used measurement tool. The prevalence of frailty in the elderly population of different countries varies from 1.5% to 43.41%. It can be partly explained by different measurement tools in each study, such as FI, Fried's phenotype, or Kihon's checklist [37–40]. Numerous tools are used to appraise frailty, but there has been no consensus on an international gold-standard measurement tool.

The socio-demographic findings of the present study were almost in line with previous studies. The majority of the frail elderly in this study were physically inactive (77.4%). A review article reported that increasing physical activity could improve frailty status and recommends increasing physical activity interventions to prevent and reverse frailty [41]. However, considering the nature of cross-sectional studies, it may be possible that being frail resulted in physical inactivity in elderly people [38]. The frail participants in our study were mostly female (82.3%) and married (61.6%), as well as previous studies [42, 43]. The predominance of frailty in females was observed in several studies and women's longer life expectancy can explain it [38, 44–46]. Moreover, due to the onset of menopause in women, physiological changes like increasing weight can trigger systemic inflammation and speed up the frailty process [47, 48]. We found 76.2% of frail people in our study were illiterate and 86% were housewives or freelancers. These results are also consistent with a large number of studies that revealed that lower socioeconomic status, such as individual and neighborhood deprivation [49], lower education [50, 51], and job status [52] are strongly associated with a higher risk of frailty. As well as frailty syndrome, depression is associated with disabilities in older adults, and their overlapping will be challenging. In the present study, PHQ-9 progressively increased among non-frail, pre-frail, and frail subjects and, it was significantly associated with frailty in the elderly population its score was 10.55 in frail individuals, which was more than two-fold of non-frails. A systematic review reported that prevalence of the depression among frail individuals increases with increasing age [53].

Previously published studies proposed that anthropometric indices are strong predictors of frailty in old populations. It is assumed that weight loss and sarcopenia are the main manifestations of frailty and obese/overweight persons are not at risk of being frail [12, 54]. However, according to our results, a high BMI increases the odds of frailty according to the FI score. Evidence showed divergent results regarding the correlation between BMI and frailty. Some studies including a recent large cohort study with 29,937 participants have shown a positive association between a higher level of BMI and a higher risk of frailty [55–59]. On the other hand, a cohort study on 6662 women in France showed that higher BMI is a protective factor against adverse outcomes in frail elderly women [60]. Another study showed a higher risk of frailty and mortality among those who have a lower BMI than 25 kg/m$^2$ [61]. So we evaluated the association between frailty (both FI and phenotype) and BMI categories (> 29 and < 24 kg/m$^2$). While results showed both high and low BMI increased FI in a crude model, after adjustment for confounding factors, a positive association

between BMI > 29 and frailty (according to FI) remained. Contrary to the BMI > 29 and FI association, BMI was a protective factor for the frailty phenotype (OR < 1). This finding could be explained by one of the Fried frailty phenotype criteria which is unintentional weight loss, It means lower weight could be regarded as a risk factor in the phenotype assessment tool. Another difference between these two instruments is that the frailty index measures cognitive function. Evidence demonstrated that losing weight improves cognitive performance especially executive function in obese and overweight subjects via mechanisms including systemic inflammation, insulin resistance, and high lipid profile [62–64]. So the effect of obesity and cognitive impairment, one of the frailty syndrome's components according to FI, might be another explanation for this observation. Two cohort studies in Taiwan and England reported a U shape relationship between BMI and frailty risk which means both wasting and obesity are correlated with frailty, and maintaining a normal BMI would be better for retaining physical ability in the elderly [65, 66]. In our analysis, a similar correlation between BMI categories and frailty was seen in our crude model, but after adjustment for confounding factors, the relationship for BMI < 24 disappeared. Despite BMI being known as a good obesity indicator globally, it can not discriminate between muscle mass and fat mass. The term "sarcopenic obesity" is defined as decreased muscle mass and increased fat mass [45] and, individuals with sarcopenic obesity tend to be more physically frail and poor [67]. In summary, adipose tissue releases a group of hormones and pro-inflammatory cytokines that contribute to the elevation of inflammatory markers, leading to systemic inflammation in the body [68–70]. Inflammation has been understood as one of the potential pathophysiological mechanisms linked with frailty [70] which affects muscle function and mobility [71]. It is hypothesized that insulin resistance and hyperinsulinemia impair muscle protein production and breakdown [72, 73]. Impaired muscle quality subsequently brings low muscle strength and energy dysregulation and decreases in performance, respectively, as seen in frailty [74].

WC and WHtR are good indicators of abdominal obesity [59, 75], and abdominal fat is associated with an increased risk of cardiovascular and metabolic disease in late adulthood [75]. Most of the studies showed a significant relationship between frailty and central obesity [20, 21]. According to previously published articles, abdominal obesity is more closely associated with a higher risk of frailty than general obesity [58]; even a study showed that subjects with low BMI but higher WC were frailer [58, 66]. WHtR is another anthropometric tool that is more accurate than WC in predicting central obesity [59]. Thus we decided to investigate the association between WHtR with frailty in this study. One key finding of the current study is that the frail group has greater waist-to-height circumference than the non-frail group. These results are consistent with previous studies [40, 45, 58]. Findings confirmed that WHtR could be a good tool to discriminate abdominal fat, which is highly associated with visceral fat [76–78] and serves cardiovascular and metabolic risks that cause co-morbidity and might increase the risk of frailty in older adults [58].

Most previously published studies reported a significant positive relationship between higher WHR and frailty risk [79–81]. A cohort study on the older population of England reported a significant relationship between high WHR and frailty risk [79, 81]. our findings showed the exact correlation between WHR and frailty, such that WHR increases the risk of frailty approximately 2.5-fold.

Newly developed obesity-related indices are proposed to reflect body composition and body fat better than traditional indices. In this study, BRI, BAI, and ABSI were calculated for each participant. Some studies have asserted that these novel anthropometric indices are associated with metabolic syndrome, osteoporosis, peripheral artery occlusive disease, and fatty liver [82–85]. According to final logistic regression models, none of the aforementioned indices were associated with FI and frailty phenotype. A systematic review investigated the validity of the BAI in predicting body fat and reported that evidence showed that BAI is not a satisfying indicator of body fat percentage in adults, which supports our results [86].

The strength of this study is that it has appraised vast types of body composition indices in the elderly, especially novel obesity-related indices such as BRI, BAI, and ABSI, and evaluated their association with frailty. Also, frailty index and frailty phenotype, the two most commonly used tools, were considered and compared together in our study. The results of this study help to recognize the anthropometric risk factors for being frail in the elderly. In addition, our investigations illustrated the prevalence of frailty and socio-demographic characteristics in a larger sample size in comparison with other studies in Iran and the Middle East [87]. This study had some limitations; first of all, some of the disabled frail subjects were unable to collaborate in our research. Moreover, it should be noted that although we adjusted the analysis for many variables, there may still be other confounding factors. Another limitation is the design of the study which could assess the cross-sectional relationships, which makes it impossible to draw causal interferences.

Overall, this study showed that the risk of frailty increases as body anthropometric indices increase and the elderly progress towards overweight and obesity. This study could help policy-makers to design interventional preventive plans to reduce frailty. Moreover, abdominal obesity indices (WC, WHR, and, WHtR) could be an appropriate tool for the evaluation of frailty in the elderly, while further studies are

needed to evaluate the utility of the newly developed anthropometric indices in older adults.

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**Authors' contributions** FS, MM, and HSE came up with the idea and designed the study. ZSH, SMA, MK, and HK contributed to collecting data. FS was the biostatistics advisor of this study. ME, FP, and HF drafted and revised the final manuscript, All of the authors read the final manuscript and approved it.

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**Data availability** The datasets generated during the current study are not publicly available due to ethical concerns but are available from the corresponding author on reasonable request.

## Declarations

**Ethics approval and consent to participate** This study was approved by the research ethical committee of Endocrinology and Metabolism Research Institute (EMRI), Tehran University of Medical Sciences ( Ethical code: IR.TUMS.EMRI.REC.1396.00158) and ethical committee of Birjand University of Medical Sciences (Ethical code: IR.BUMS.Rec.1397.282) written informed consent was obtained from all participants before participation. All methods were carried out in accordance with relevant institutional guidelines and regulations.

**Consent for publication** Not applicable.

**Competing Interests** The authors declared that they have no conflict of interest.

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