Huang *et al. BMC Geriatrics* (2025) 25:370
https://doi.org/10.1186/s12877-025-05974-x

BMC Geriatrics

RESEARCH

Open Access

Impact of body composition on fragility fractures in US elderly adults: a population-based study

Xiaohong Huang[1,2*†], Dongxu Zhu[2,3†], Tianrui Wang[3], Xiaodong Lian[4] and Yingze Zhang[1,2,3,4*]

Abstract

Objectives The aim of this study was to investigate how variations in body composition impact the likelihood and location of fragility fractures in older adults.

Methods Data of US adults aged ≥ 60 years with fragility fracture and body dimension records (*n* = 13177, representing approximately 334 million US elderly adults) were from NHANES between 1999 and March 2020. We calculated body composition parameters, including the body roundness index (BRI), weight-adjusted waist index (WWI), abdominal visceral fat index (AVI), and arm-to-waist circumference ratio (AC/WC). Linear regression analyzed trends in site-specific fragility fractures, while logistic regression assessed the separate and joint effects of parameters.

Results Fragility fractures increased, especially among elderly with central obesity. A rounded body shape ($OR_{4.42 \le BRI \le 5.60}$ = 0.6, 95% CI, 0.4–0.9; $OR_{5.61 \le BRI \le 7.00}$ = 0.5, 95% CI, 0.3–0.8; $OR_{BRI \ge 7.01}$ = 0.4, 95% CI, 0.2–0.8) and a balanced arm-to-waist size ($OR_{0.32 \le AC/WC \le 0.33}$ = 0.6, 95% CI, 0.4–0.9) reduced the risk of hip fractures, and a moderate fat content ($OR_{11.45\ cm/\sqrt{kg} \le WWI \le 1.93\ cm/\sqrt{kg}}$ = 0.6; 95% CI, 0.4–1.0) lowered the risk of vertebral fractures. Joint analyses found that moderate-built ($OR_{BRI < 4.42,\ 10.96\ cm/\sqrt{kg} \le WWI \le 11.44\ cm/\sqrt{kg}}$ = 1.9, 95% CI, 1.3–3.0) elderly faced doubled risk of hip fractures compared to those with severe central obesity (BRI ≥ 7.01, WWI 11.45–11.93 cm/√kg), while mild obesity ($OR_{5.61 \le BRI \le 7.00,\ WWI < 10.96\ cm/\sqrt{kg}}$ = 0.1, 95% CI, 0.0–0.6) carried only 10% of this risk. A stocky physique ($OR_{BRI \ge 7.01,\ AVI\ 20.48–23.44\ cm^2/1000}$ = 3.6, 95% CI, 1.1–11.1) was a significant risk factor for vertebral fragility fractures, while fit individuals with strong arms ($OR_{BRI < 4.42,\ AC/WC \ge 0.34}$ = 0.7, 95% CI, 0.5–1.0) experienced a lower incidence of vertebral fractures.

Conclusions This population-based cohort study identified distinct risk groups for fragility fractures and clearly visualized these high-risk populations, which contributes to preventing fragility fractures and reduce the risk of second fractures.

Keywords Fragility fracture, Obesity, Body roundness index, Weight-adjusted waist index, Abdominal visceral fat index, Arm-to-waist circumference ratio.

†Xiaohong Huang and Dongxu Zhu are contribute equally to the work.

*Correspondence:
Xiaohong Huang
ysrred@gmail.com
Yingze Zhang
dryzzhang@hotmail.com

[1]Shandong Institute of Traumatic Orthopedics, Medical Research Center, The Affiliated Hospital of Qingdao University, Qingdao, China
[2]Orthopedic Institute of Medicine–Engineering, Innovation, and Translation, Qingdao University, Qingdao, China
[3]Knee Preservation Center, Department of Orthopedics, The Affiliated Hospital of Qingdao University, Qingdao, China
[4]Department of Orthopedics, The Third Hospital of Hebei Medical University, Shijiazhuang, China

Background

Fragility fractures, particularly of the hip and spine, are serious complications of osteoporosis. Wrist fractures are common and result in loss of function and an increased risk of hip fracture [1]. For hip fractures, the 30-day cumulative mortality rate is between 5% and 10%, and a year after surgery, the rate can increase to approximately 30% [2]. Vertebral compression fractures double the mortality rate, with rates of 7.2% and 10.5% in women at one and two years and 14.6% and 20.6% in men [3]. Given global aging, preventing fractures is critical to improving longevity and quality of life.

Muscle mass declines after age 40, while fat increases with age [4]. Obesity increases stress on weight-bearing bones such as the hip and spine, increasing the risk of fractures [5]. Although adipose tissues produce protective adipokines, visceral fat is associated with higher levels of inflammatory cytokines and hormones that negatively impact bone mineral density (BMD) [6]. Studies show that obese women who typically experience hip, vertebral, and pelvic fractures are younger than normal-weight or underweight women, while wrist fractures are more common in older women with obesity [7]. BMI is not an adequate measure of obesity because it does not take into account variations in fat-to-muscle ratio and fat distribution [8], highlighting the need for an alternative assessment method. Differences in body composition affect bone metabolism, stress distribution, balance and fall patterns, and the likelihood and location of fragility fractures.

This study attempts to conduct a comprehensive assessment of body composition using body dimension records. Body roundness index (BRI) is used to assess body shape in the context of metabolic diseases, such as hypertension [9] and cardiovascular health [10]. Weight-adjusted waist index (WWI) is employed to estimate overall body fat, serving as an integrated measure for fat, muscle, and bone health [11]. Additionally, abdominal visceral fat index (AVI) provides insights into the risk of metabolic diseases associated with excess visceral fat [12]. The arm-to-waist circumference ratio (AC/WC) helps identify individuals with disproportionate fat distribution [13]. The main objective of this study is to investigate how body composition affects site-specific fragility fractures and to provide a readily apparent method for assessing fracture risk in elderly adults. Specifically, we examined: (1) the prevalence of site-specific fragility fractures among US elderly adults; (2) the influence of body roundness, overall body fat, and fat distribution on these fractures; and (3) the joint associations of these body composition metrics for hip and vertebral fracture risk profiling in at-risk elderly individuals.

Methods

Data source and study population

We analyzed data from the National Health and Nutrition Examination Survey (NHANES), a nationally representative survey conducted in twelve two-year cycles from 1999 to March 2020. Participants in NHANES provided written informed consent and study protocols were approved by the Research Ethics Review Board of the National Center for Health Statistics. We focused on cycles with bone fracture information. Eight cycles (1999–2000, 2001–2002, 2003–2004, 2005–2006, 2007–2008, 2009–2010, 2013–2014, 2017–March 2020) were included. The study sample was limited to older adults (age ≥ 60 years), with the clear answer being "broken or fractured a hip/wrist/spine" (yes/no).

Fragility fractures

Participants with a history of fragility fractures were defined as: (1) those who had a hip, wrist, or vertebral fracture, (2) excluding fractures caused by accidents or hard falls, and (3) excluding fractures that occurred before their age 50. Conversely, participants without a history of fragility fractures were defined as: (1) those who had not sustained a hip, wrist, or vertebral fracture, or (2) those who had sustained such fractures but attributed them to accidents or hard falls. In addition, the overall fragility fractures were determined by aggregating reported incident hip, wrist, and vertebral fractures.

Anthropometry and body composition

Body measurements, including weight, height, waist circumference (WC), arm circumference, and body mass index (BMI), were obtained from the examination data. BMI was used to assess general obesity, which was categorized as follows: underweight (< 18.5 kg/m^2), normal weight (18.5–24.9 kg/m^2), overweight (25–29.9 kg/m^2), and obese (≥ 30 kg/m^2) [14]. In addition, WC serves as a measure of central adiposity, defined as ≥ 102 cm for men and ≥ 89 cm for women [15]. To provide a comprehensive overview of participants' body composition, we calculated BRI [16], WWI [17], AVI [18], and AC/WC [13] using body weight, height, WC, and arm circumference.

Covariates

Demographic information regarding age, sex, and race/ethnicity was collected. Age was divided into the following groups: 60–69, 70–79, and ≥ 80 years. Race/ethnicity was classified as non-Hispanic white, non-Hispanic black, Hispanic, and other (including multiple races).

Study outcomes

The primary outcome of this study was to provide a comprehensive assessment of body shape, total body fat, and fat distribution in relation to the risk of site-specific fragility fractures, i.e., the separate and joint effects of body composition on these fractures. In addition, we examined trends in the prevalence of fragility fractures in relation to demographic characteristics and body composition.

Statistical analysis

Prevalence rates and 95% confidence intervals (CIs) were reported for categorical variables. The chi-square test (χ^2) was used to assess the distribution consistency of categorical variables between elderly individuals with and without a history of fragility fractures. A crude weighted trend in the prevalence of fragility fractures across survey cycles was examined using a linear regression model, treating the combined survey cycle as a continuous variable. Statistical significance was set at $p < 0.05$.

Due to the lack of reference ranges for the elderly population, the numeric parameters of body composition were divided into four quartiles and treated as categorical variables for further analysis. Interactions between variables were assessed using a logistic regression model. To evaluate the separate and joint effects of body shape, total body fat, and fat distribution on site-specific fragility fractures, a weighted logistic regression model adjusted for age, sex, and race/ethnicity was applied. To illustrate the risks associated with each variable, odds ratios (ORs) and corresponding 95% CIs were presented. A $p < 0.05$ was considered indicate the statistical significance of this risk.

Sensitivity analyses for the separate effects of body composition on site-specific fragility fractures were performed (1) by excluding participants aged ≥ 80 years, (2) using a multivariable regression model adjusted for BMI, WC and covariates. In addition, sensitivity analyses were performed for the joint effects of body composition parameters on hip or vertebral fragility fractures by adjusting for a single body composition parameter alongside covariates.

Data analysis for this study used rigorous methods suited for structured survey data, including stratification, clustering, and weighting to ensure nationally representative estimates. Statistical analyses were performed using SAS software (version 9.4). Python (version 9.3) was used to generate diagrams. Analyses were conducted from January 1, 2024, to August 1, 2024.

Table 1 Baseline characteristics of participants in this study.[a]

Variable	Subgroup	% (95% CI)
Fragility fracture history	Overall	15.1 (14.1–16.0)
	Hip	1.9 (1.6–2.1)
	Wrist	11.2 (10.5–11.9)
	Spine	3.1 (2.6–3.5)
Age, y	60–69	52.2 (50.8–53.6)
	70–79	32.0 (31.0–33.0)
	≥ 80	15.8 (14.9–16.8)
Sex	Male	45.4 (44.5–46.2)
	Female	54.6 (53.8–55.5)
Race/ethnicity	Non-Hispanic white	79.4 (77.1–81.8)
	Non-Hispanic black	8.5 (7.2–9.7)
	Hispanic	7.3 (6.0–8.7)
	Other	4.8 (4.0–5.5)
BMI, kg/m²	< 18.5	1.2 (1.0–1.4)
	18.5–24.9	25.6 (24.5–26.8)
	25–29.9	37.2 (36.0–38.4)
	≥ 30	35.9 (34.6–37.3)
WC, cm	< 102/89	33.6 (32.3–34.9)
	≥ 102/89	66.4 (65.1–67.7)

[a]Data from NHANES. Data are weighted to be nationally representative. Data are present as prevalence (%, 95% CI) unless indicated otherwise

Results

Baseline characteristics

We identified 13,177 individuals representing approximately 334 million noninstitutionalized US elderly adults (Figure S1). Approximately 70% of the participants were above normal weight, with 37.2% (95% CI, 36.0–38.4%) classified as overweight and 35.9% (95% CI, 34.6–37.3%) as obese, and only 1.2% (95% CI, 1.0–1.4%) of the elderly were underweight (Table 1). In addition, more than 60% of participants were central obesity, with a WC of 102 cm or more in men and 89 cm or more in women, totaling 66.4% (95% CI, 65.1–67.7%). Between 1999 and March 2020, 15.1% (95% CI, 14.1–16.0%) of the US elderly reported a history of fragility fractures. Amongst, 1.9% (95% CI, 1.6–2.1%) experienced hip fractures, 11.2% (95% CI, 10.5–11.9%) had wrist fractures, and 3.1% (95% CI, 2.6–3.5%) had vertebral fractures. Fragility fractures were consistently distributed across the BMI and WC categories (Table S1).

Trends in fragility fractures among US elderly adults

An increase was noted in the overall prevalence of fragility fractures (Fig. 1A, Table S2), combining reported incident hip, wrist, and vertebral fractures. The prevalence of overall fragility fractures increased by 4%, from 14.0% (95% CI, 12.5–15.5%) in 1999–2002 to 18.0% (95% CI, 15.9–20.0%) in 2017–March 2020. Among the findings, the trend in vertebral fragility fractures showed an increase, while the rates of hip and wrist fragility fractures remained stable. By BMI and WC categories, fluctuating upward trends in the overall prevalence of fragility fractures were observed in the high-BMI and high-WC groups (Fig. 1B and C, Table S3). Regarding site-specific fragility fractures, consistent increases were noted in older individuals with a high-BMI (BMI ≥ 30 kg/m²) or a high-WC (WC ≥ 102/89 cm) for wrist fragility fractures (Figure S2, Table S4).

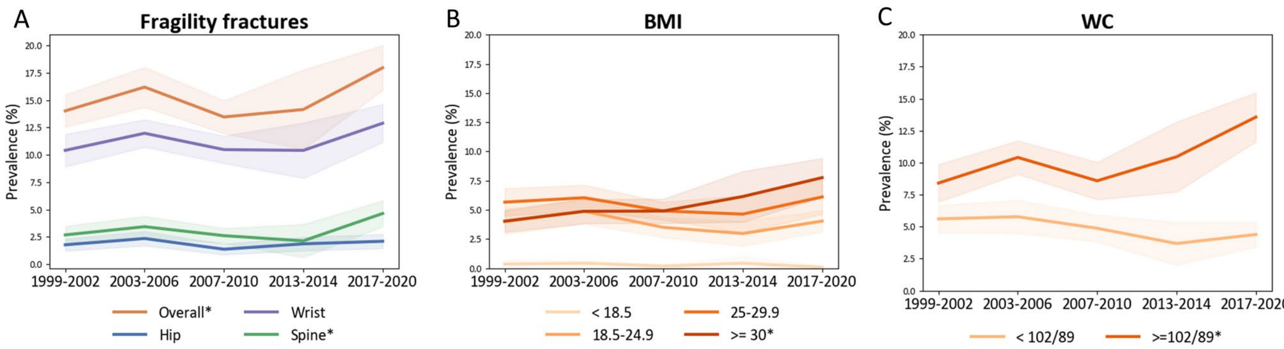

Fig. 1 Crude weighted prevalence in fragility fractures among US elderly adults, 1999–March 2020. (**A**) Prevalence in fragility fractures. (**B**) Prevalence in overall fragility fractures by BMI. (**C**) Prevalence in overall fragility fractures by WC. *The prevalence alters during this period, with a p-trend < 0.05

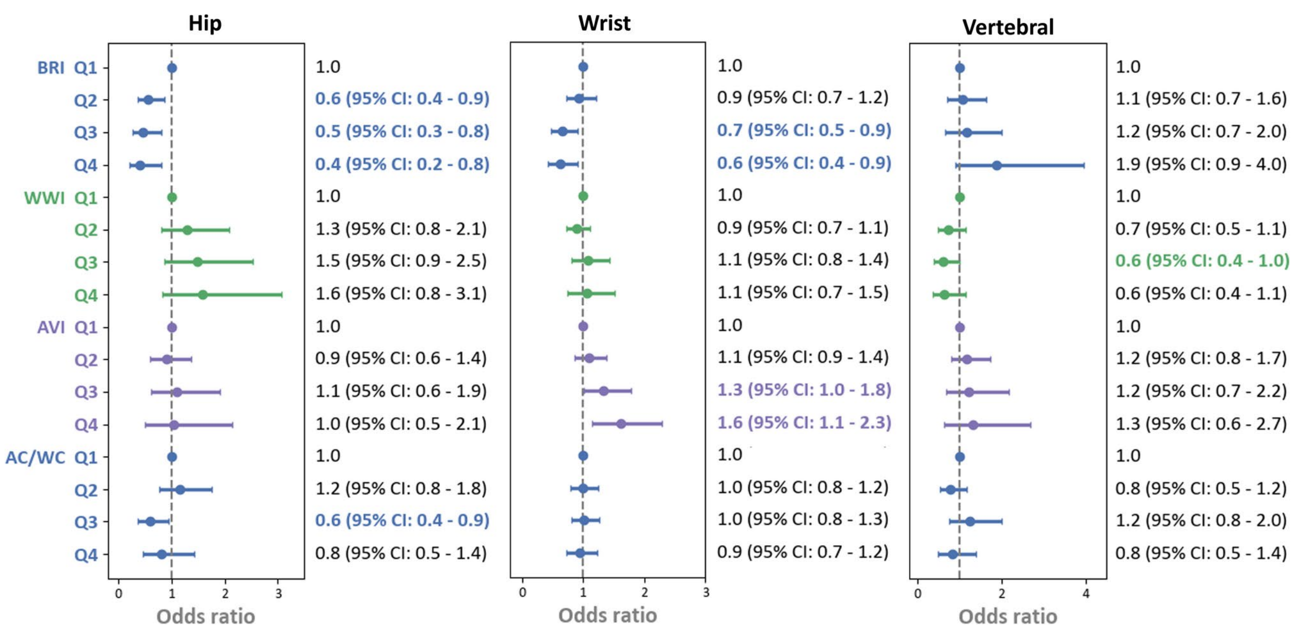

Fig. 2 Separate effect of body composition on site-specific fragility fractures among US elderly adults, 1999–March 2020. Weighted logistic regression models were adjusted for body composition parameters (BRI, WWI, AVI, and AC/WC) and covariates (age, sex, and race/ethnicity). The OR and 95% CI for each subgroup are presented in color for $p < 0.05$ and in black for $p \geq 0.05$

Separate effect of body composition on fragility fractures

Q1 was used as a reference when examining the separate effect of body composition on site-specific fragility fractures in Model 1 (Table S5). In hip fragility fractures, a higher BRI exhibited a protective role ($OR_{4.42 \leq BRI \leq 5.60}$ = 0.6, 95% CI, 0.4–0.9; $OR_{5.61 \leq BRI \leq 7.00}$ = 0.5, 95% CI, 0.3–0.8; $OR_{BRI \geq 7.01}$ = 0.4, 95% CI, 0.2–0.8; Fig. 2, Table S6.1). Furthermore, a moderate AC/WC ratio provided protective benefits ($OR_{0.32 \leq AC/WC \leq 0.33}$ = 0.6, 95% CI, 0.4–0.9; Fig. 2, Table S6.1). This finding is consistent with the distribution and crude weighted trend in the prevalence of hip fragility fractures observed across AC/WC categories (Figure S3, Tables S7 and S8). Specifically, the prevalence of hip fragility fractures was lowest in the moderate AC/WC group among elderly individuals with a history of hip fragility fractures (Table S7). Furthermore, the prevalence of hip fragility fractures showed a dynamic increase in both the low and high AC/WC groups, while remaining stable in the medium and moderate groups (Figure S3, Table S8). In the context of wrist fragility fractures, both moderate and high BRI demonstrated protective effects, while moderate and high AVI posed risks ($OR_{5.61 \leq BRI \leq 7.00}$ = 0.7, 95% CI, 0.5–0.9; $OR_{BRI \geq 7.01}$, 95% CI, 0.4–0.9; $OR_{23.45\ cm^2/1000 \leq AVI \leq 26.96\ cm^2/1000}$ = 1.3, 95% CI, 1.0–1.8; $OR_{AVI \geq 26.97}$ = 1.6, 95% CI, 1.2–2.3; Fig. 2, Table S6.2). Notably, an upward trend in wrist fragility fractures was observed in the high BRI and high AVI groups (Figure S3, Table S8). Regarding vertebral fragility fractures, a significant association was found among elderly individuals with a moderate WWI, yielding an OR of 0.6 ($OR_{11.45 \leq WWI \leq 11.93\ cm/\sqrt{kg}}$ = 0.6, 95% CI, 0.4–1.0; Fig. 2, Table S6.3). Consistently, a dynamic change in the prevalence of vertebral fragility fractures was observed in the elderly population with low and medium WWI

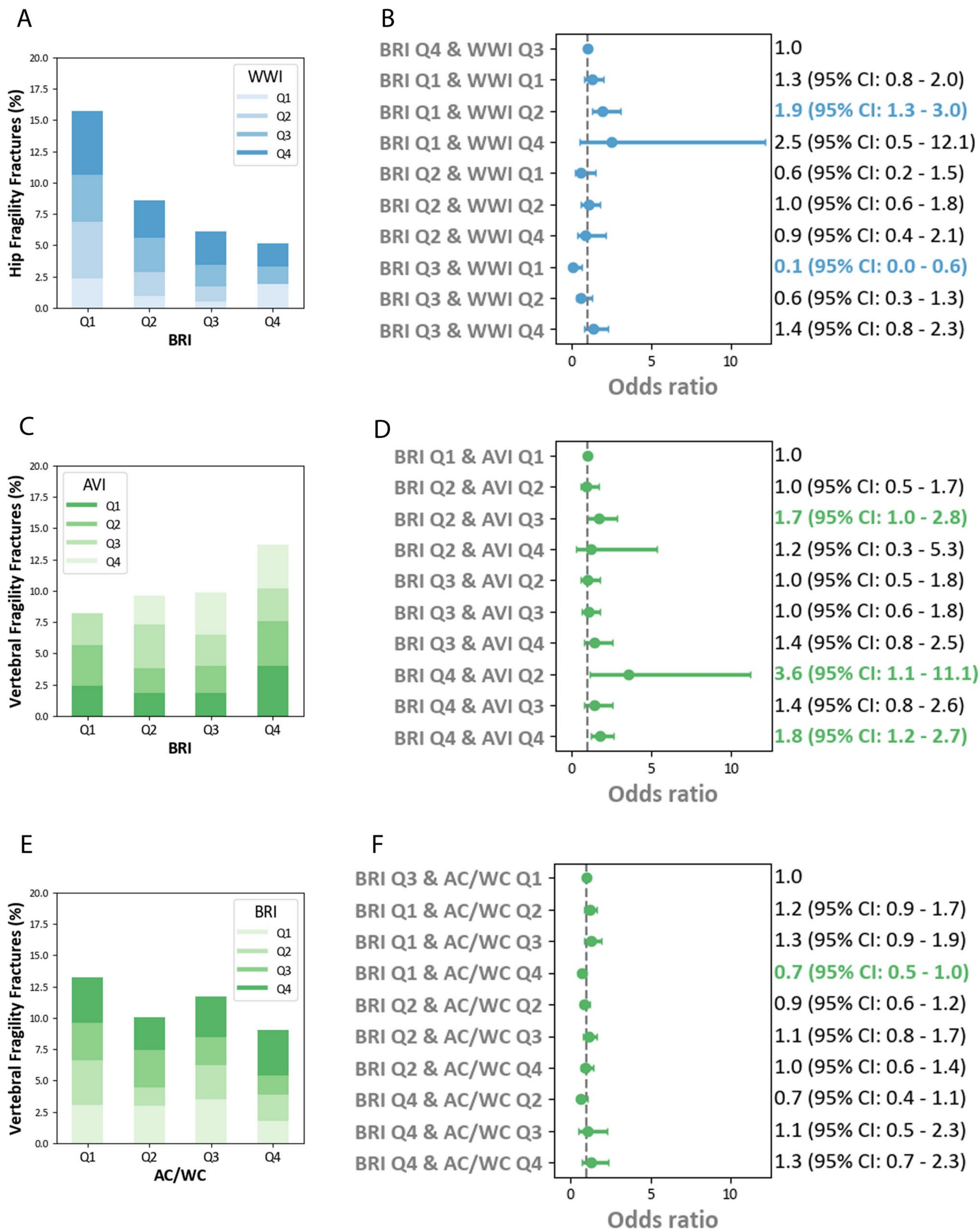

Fig. 3 (See legend on next page.)

(See figure on previous page.)

Fig. 3 Joint effects of body composition on hip and vertebral fragility fractures. The stacked graphs charts illustrate the prevalence of (**A**) hip fragility fractures in the BRI and WWI groups, **C**) vertebral fragility fractures in the BRI and AVI groups, and vertebral fragility fractures in the BRI and AC/WC groups. The forest plots reveal (**B**) the joint association of BRI and WWI in hip fragility fractures, **D**) the joint association of BRI and AVI in vertebral fragility fractures, and F) the joint association of BRI and AC/WC in vertebral fragility fractures. The OR and 95% CI for each joint group are presented in color for $p < 0.05$ and in black for $p \geq 0.05$

levels, while no such change was noted in the moderate and high WWI categories during the period 1999–March 2020 (Figure S3, Table S8).

When adjusted for an individual body composition parameter (Model 2, Model 3, Model 4, Model 5), most significant estimates for hip, wrist, and vertebral fragility fractures were lost (Tables S6.1, S6.2, S6.3). Ruling out the possibility of collinearity among body composition parameters (Table S6.5), there may be interactions between these parameters and covariates (Table S11) as well as joint association among these parameters (Table S12).

Age is a significant risk factor for fragility fractures, as demonstrated by the uneven distribution of prevalence in both overall fragility fractures and site-specific fractures, along with increasing incidence rates among older adults (Figure S2, Tables S1, S3 and S4). The association results remained robust after excluding participants ≥ 80 years in Model 6. The protective roles of BRI and AC/WC continued to demonstrate effectiveness in preventing hip fragility fractures, and high BRI was linked to a reduced risk of wrist fragility fractures, although the significant estimate for WWI in preventing vertebral fragility fractures was absent (Table S9). The relationship of BMI and WC with site-specific fragility fractures was further analyzed in Model 7. No significant associations were observed for hip and vertebral fragility fractures, which are among the most serious events (Table S10). Additionally, being underweight, overweight, or obese was linked to a higher risk of wrist fragility fractures compared to normal weight, although this relationship lacks clear directionality (Table S10).

Joint effect of body composition on fragility fractures

An interaction between BRI and WWI was found in hip fragility fractures (Table S12). The prevalence of hip fragility fractures decreased across the BRI categories from Q1 to Q4, with individuals exhibiting a low BRI and high WWI (BRI < 4.42, WWI ≥ 11.94 cm/√kg) representing a significant proportion of hip fragility fractures (Fig. 3A). Model 8 showed that the OR for hip fragility fractures among elderly individuals with a combination of low BRI and medium WWI was 1.9 times of those with a high BRI and moderate WWI (BRI ≥ 7.01, WWI 11.45–11.93 cm/√kg); in contrast, a moderate BRI and low WWI reduced that risk by 90% ($OR_{BRI < 4.42,\ 10.96 \leq WWI \leq 11.44\ cm/\sqrt{kg}}$ = 1.9, 95% CI, 1.3–3.0; $OR_{5.61 \leq BRI \leq 7.00,\ WWI < 10.96\ cm/\sqrt{kg}}$ = 0.1, 95% CI, 0.0–0.6; Fig. 3B, Table S13.1). In general, the anthropometric measurements for the corresponding joint groups indicated that moderate-built elderly faced a risk almost one-fold higher compared to that of those with severe central obesity, while mild obese individuals faced a risk of hip fractures that is only 10% of that seen in individuals with severe central obesity (Table S13.2). In the sensitivity analysis, the ORs for BRI (Model 2) or WWI (Model 3) were adjusted along with various covariates (Table S6.1). The absence of significant estimates suggests that the joint effect of BRI and WWI may be a predominant factor influencing hip fragility fractures.

An interaction between BRI and AVI was identified concerning vertebral fragility fractures (Table S12, Table S13.3 and S13.5). Unlike hip fragility fractures, the prevalence of vertebral fragility fractures increased as BRI rose from Q1 to Q4 (Fig. 3C). Using a low BRI and low AVI (BRI < 4.42, AVI < 20.48 cm²/1000) as a reference in Model 9, the ORs for elderly individuals with a medium BRI and moderate AVI and those with a high BRI and high AVI approximately doubled ($OR_{4.42 \leq BRI \leq 5.60,\ 23.45 \leq AVI \leq 26.96\ cm^2/1000}$ = 1.7, 95% CI, 1.0–2.8; $OR_{BRI \geq 7.01,\ AVI \geq 26.97\ cm^2/1000}$ = 1.8, 95% CI, 1.2–2.7; Fig. 3D, Table S13.3). Furthermore, in the elderly group with a high BRI and medium AVI, the OR for vertebral fragility fractures increased 2.6-fold ($OR_{BRI \geq 7.01,\ 20.48 \leq AVI \leq 23.444\ cm^2/1000}$ = 3.6, 95% CI, 1.1–11.1; Fig. 3D, Table S13.3). Overall, the anthropometric measurements showed that individuals who were tall and overweight, as well as those who were with morbidly obesity, had a higher risk of vertebral fragility fractures, and the risk was highest among stocky-built individuals, compared to their lean physique counterparts (Table S13.4). In the sensitivity analysis, ORs for BRI (Model 2) or AVI (Model 4) were adjusted along with covariates (Table S6.3). Significant estimates were found in the high BRI group in Model 2 and the high AVI group in Model 4, while both of which had lower akaike information criterion (AIC) values compared to Model 9. Moreover, the interaction between BRI and AC/WC was also identified (Table S12). Using a moderate BRI and low AC/WC (5.61 ≤ BRI ≤ 7.00, AC/WC < 0.30) as a reference in Model 10, the OR for elderly individuals with a low BRI and high AC/WC was decreased ($OR_{BRI < 4.42,\ AC/WC \geq 0.34}$ = 0.7, 95% CI, 0.5–1.0; Fig. 3F, Table S13.5). Hence, fit individuals with strong arms experienced a lower incidence of vertebral fractures (Fig. 3E), compared to their counterparts with abdominal obesity and a lack of exercise (Table S13.6). Although an interaction between AVI and

AC/WC was found (Table S12), no joint effect (Model 11) was significant when adjusted for age, sex, and race/ethnicity (Table S13.7).

The interaction of body composition parameters in wrist fragility fractures was identified (Table S12). However, due to the higher randomness of wrist fractures, which are influenced by a complex interplay of various contributing circumstances, as well as intrinsic factors like bone loss, no further exploration was conducted in this study.

Discussion

Principal findings

Fragility fractures occur when bones cannot withstand changes in pressure. The risk is influenced by factors such as bone microstructure, bone shape, abdominal tension, and fall patterns. By assessing body composition using BRI, WWI, AVI and AC/WC in US elderly adults, we examined various aspects of body composition and associated fracture risks. This population-based cohort study identifies distinct risk groups for fragility fractures, particularly in the hip and spine, and clearly visualizes these high-risk populations.

Falls account for 95% of hip fractures [19], and distal radius fractures are commonly caused by falls onto the outstretched hand and lifting heavy objects [20]. A rounded body shape and or greater muscle strength, particularly in the upper arms, may protect against fractures by helping to restore balance after a fall [21, 22]. People aged 60 years and older generally suffer from sarcopenia [23]. Studies show that age-related loss accounts for up to 42% of muscle mass between the ages of 30 and 80, with a particularly rapid decline observed after the age of 50 [24]. Sarcopenia increases the risk of falls and hip fractures [25]. Simultaneously, an increase in appendicular skeletal muscle, but not body fat mass, is significantly associated with a lower risk of osteoporotic fractures, especially hip fractures [26]. Paralleled with the finding of this study, it has been reported that visceral obesity is a significant risk factor for wrist fractures as it promotes bone loss and impairs balance in the elderly [27, 28]. However, subcutaneous adipose tissues, which may be linked to favorable bone properties, have been associated with a higher areal BMD in the spine and hip [29]. This may explain why mild obesity a lower risk of hip fractures had compared to severe central obesity and a slim abdominal build.

Vertebral compression fractures can be caused by low-level stress or routine activities [30] such as lifting heavy objects or even sneezing. Increased abdominal pressure due to obesity or chronic diseases impairs load distribution on the spine and disrupts bone metabolism, increasing the risk of vertebral compression fractures [31–33]. Although the effects of chest pressure on bone health is less clear, chronic conditions such as persistent cough in osteoporotic individuals increase the risk of fragility fractures [34]. Internal abdominal and thoracic pressure has a significant impact on fragility fractures by altering bone quality and load distribution. Moreover, fat around the trunk cushions falls and absorbs shock, potentially reducing the risk of vertebral fractures [35]. Moderate body fat percentage has also been reported to be associated with higher BMD and improved bone health due to the beneficial effects of hormones and adipokine [36, 37]. However, it has been estimated that a 10 cm increase in WC elevates the risk of vertebral fractures by 3% [38]. The study therefore suggests that, unlike hip fractures, increased body roundness, possibly caused by visceral abdominal fat, affects the risk of vertebral fractures. Conversely, elderly with a moderate body fat percentage, likely due to subcutaneous fat, have a lower risk of vertebral fractures, rather than morbid obesity compared to their lean counterparts. And the likelihood of spinal compression fractures increases with height due to greater gravitation loading, potentially lower BMD, uneven mechanical stress distribution due to posture, and increased risk of age-related osteoporosis [39].

Limitations

In addition to the strengths of this study, including comprehensive analyses of nationally representative samples and body composition factors, several limitations should be acknowledged. First, the lack of records from the 2011–2012 and 2015–2016 osteoporosis questionnaires impedes the continuous analysis of national trends from 1999 to 2020, which may due to changes in questionnaire design, delays in data release, and issues related to sample size or data completeness. Second, the cross-sectional design of the study limits the ability to determine causal relationships between obesity types and fragility fractures. Third, incomplete data on thigh and hip circumference hinders the study of how lower body obesity may influence hip, vertebral, and wrist fractures. Fourth, fragility fractures also occur in sites like the humerus, ribs, clavicle and pelvis, which were not included in this study due to data availability in NHANES. Finally, the study does not take into account confounding factors such as physical activity, genetic predisposition, and chronic diseases that could influence the observed associations.

Implications for practice and researchers

This approach helps identify high-risk groups for fragility fractures, particularly of the hip and spine, in the elderly. Interventions should focus on strength training and balance exercises tailored to these populations to improve muscle quality and stability and prevent fractures. In addition, it is important to educate seniors on healthy lifestyle, such as proper nutrition and regular physical activity. Regular exercise has been reported to remodel the abdominal subcutaneous adipose tissue, increasing its angiogenic capacity and lipid storage capacity, thus counteracting abnormalities associated with obesity-related health complications [40]. Moreover, these findings offer valuable insights for the practice of fragility fractures, allow for individualized surgical planning, and improve risk assessment by predicting healing capabilities and complications. It informs tailored postoperative rehabilitation strategies, particularly for patients with a higher body fat percentage.

Conclusion

The roundness of the body serves a dual purpose. It may offer protection against hip fractures by facilitating balance, yet higher body roundness levels are associated with an increased risk of vertebral compression fractures, which potentially due to the fat-induced stress and chronic inflammation from adipose tissues. The population-based cohort study introduces a quick and accessible assessment of body composition, which is suitable for initial screening. And the outcome of this study establishes specific risk thresholds for fragility fractures, particularly given that 70% of elderly adults were overweight or obese in the US during 1999–March 2020. Our findings highlight the importance of personalized intervention strategies that take into account body roundness, fat-to-muscle ratio, waist circumference, and arm strength. These tailored approaches can effectively reduce fracture risk, extend longevity, and improve quality of life, while promoting healthier aging and emphasizing the need for individualized care.

Abbreviations

AC/WC	Arm-to-waist circumference ratio
AVI	Abdominal visceral fat index
BMD	Bone mineral density
BMI	Body mass index
BRI	Body roundness index
CIs	Confidence intervals
NHANES	National Health and Nutrition Examination Survey
ORs	Odds ratios
WC	Waist circumference
WWI	Weight-adjusted waist index

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12877-025-05974-x.

Supplementary Material 1

Acknowledgements

None.

Author contributions

XH designed the study. XH, DZ, TW and XL performed data processing, drafted the original manuscript, and revised the manuscript. YZ supervised the entire process and approved the final version.

Funding

This research received no funding.

Data availability

This is a secondary analysis. The datasets generated and analyzed in this study are available in the NHANES database, https://www.cdc.gov/nchs/nhanes/index.htm.

Declarations

Ethics approval and consent to participate

Data were obtained from NHANES. Participants in NHANES provided written informed consent and study protocols were approved by the National Center for Health Statistics Research Ethics Review Board. This is a secondary analysis of anonymized data. Informed consent and institutional review board approval were not required.

Consent for publication

Authors have read and agreed to the published version of the manuscript.

Competing interests

The authors declare no competing interests.

Received: 18 December 2024 / Accepted: 21 April 2025
Published online: 23 May 2025

References

1. Forde C, Nicolson PJ, Vye C, Pun JC, Sheehan W, Costa ML, Lamb SE, Keene DJ. Lower limb muscle strength and balance in older adults with a distal radius fracture: a systematic review. BMC Musculoskelet Disord. 2023;24(1):741.
2. Curry SJ, Krist AH, Owens DK, Barry MJ, Caughey AB, Davidson KW, Doubeni CA, Epling JW, Kemper AR, Kubik M. Screening for osteoporosis to prevent fractures: US preventive services task force recommendation statement. JAMA. 2018;319(24):2521–31.
3. Tai T-W, Tsai Y-L, Shih C-A, Li C-C, Chang Y-F, Huang C-F, Cheng T-T, Hwang J-S, Lu T-H, Wu C-H. Refracture risk and all-cause mortality after vertebral fragility fractures: Anti-osteoporotic medications matter. J Formos Med Assoc. 2023;122:S65–73.
4. Lee Y, Ahn S, Han M, Lee JA, Ahn JY, Jeong SJ, Ku NS, Choi JY, Yeom J-S, Park SH. The obesity paradox in younger adult patients with sepsis: analysis of the MIMIC-IV database. Int J Obes 2024:1–8.
5. Gutiérrez-González R, Royuela A, Zamarron A. Survival following vertebral compression fractures in population over 65 years old. Aging Clin Exp Res. 2023;35(8):1609–17.
6. Sang Wouk C, Seungjin B, Sookyeong H, Chang Oh K, Hyeon Chang K, Yumie R, Namki H. Metabolic phenotyping with computed tomography deep learning for metabolic syndrome, osteoporosis and sarcopenia predicts mortality in adults. J Cachexia Sarcopenia Muscle 2024, 15(4).
7. Daniel P-A, Melissa OP, Francesc FA, Eduard H, Daniel M-L, Cristina C-A, Xavier N, Juliet EC, Adolfo D-P. The association between fracture and obesity is site-dependent: a population-based study in postmenopausal women. JBMR 2011, 27(2).
8. Beyene HB, Giles C, Huynh K, Wang T, Cinel M, Mellett NA, Olshansky G, Meikle TG, Watts GF, Hung J. Metabolic phenotyping of BMI to characterize cardiometabolic risk: evidence from large population-based cohorts. Nat Commun. 2023;14(1):6280.
9. Calderón-García JF, Roncero-Martín R, Rico-Martín S, De Nicolás-Jiménez JM, López-Espuela F, Santano-Mogena E, Alfageme-García P, Sanchez Munoz-Torrero JF. Effectiveness of body roundness index (BRI) and a body shape index (ABSI) in predicting hypertension: a systematic review and meta-analysis of observational studies. Int J Environ Res Public Health. 2021;18(21):11607.
10. Maessen MF, Eijsvogels TM, Verheggen RJ, Hopman MT, Verbeek AL. Vegt Fd: entering a new era of body indices: the feasibility of a body shape index and body roundness index to identify cardiovascular health status. PLoS ONE. 2014;9(9):e107212.
11. Kim KJ, Son S, Kim KJ, Kim SG, Kim NH. Weight-adjusted waist as an integrated index for fat, muscle and bone health in adults. J Cachexia Sarcopenia Muscle. 2023;14(5):2196–203.

12. Luo Y, Zhan X, Liu Y, Chen L, Zhu L, Cai W. Predicted visceral adiposity index in relation to risk of coronary heart disease and all-cause mortality: insights from NHANES. Front Endocrinol. 2024;14:1296398.
13. Xiao X, Yu X, Zhu H, Zhai X, Li S, Ma W, Ouyang M, Liu K, Eshak ES, Cao J. Arm circumference, arm-to-waist ratio in relation to cardiovascular and all-cause mortality among patients with diabetes mellitus. Nutrients. 2023;15(4):961.
14. Nuttall FQ. Body mass index: obesity, BMI, and health: a critical review. Nutr Today. 2015;50(3):117–28.
15. Lean M, Han T, Morrison C. Waist circumference as a measure for indicating need for weight management. BMJ. 1995;311(6998):158–61.
16. Zhang X, Ma N, Lin Q, Chen K, Zheng F, Wu J, Dong X, Niu W. Body roundness index and All-Cause mortality among US adults. JAMA Netw Open. 2024;7(6):e2415051.
17. Kim NH, Park Y, Kim NH, Kim SG. Weight-adjusted waist index reflects fat and muscle mass in the opposite direction in older adults. Age Ageing. 2021;50(3):780–6.
18. Lokpo SY, Amenyega W, Doe P, Osei-Yeboah J, Owiredu WK, Obirikorang C, Adu EA, Agordoh PD, Ativi E, Kortei NK. Abdominal volume index is a better predictor of visceral fat in patients with type 2 diabetes: a cross-sectional study in Ho municipality, Ghana. Alexandria J Med. 2022;58(1):85–91.
19. Women RHFAO. Reducing falls and resulting hip fractures among older women. MMWR. 2000;49(RR02):1–12.
20. MacIntyre NJ, Dewan N. Epidemiology of distal radius fractures and factors predicting risk and prognosis. Hand Ther. 2016;29(2):136–45.
21. Pijnappels M, Kingma I, Wezenberg D, Reurink G, Van Dieën JH. Armed against falls: the contribution of arm movements to balance recovery after tripping. Exp Brain Res. 2010;201:689–99.
22. Milosevic M, McConville KMV, Masani K. Arm movement improves performance in clinical balance and mobility tests. Gait Posture. 2011;33(3):507–9.
23. Benz E, Pinel A, Guillet C, Capel F, Pereira B, De Antonio M, Pouget M, Cruz-Jentoft AJ, Eglseer D, Topinkova E. Sarcopenia and sarcopenic obesity and mortality among older people. JAMA Netw Open. 2024;7(3):e243604.
24. Volpi E, Nazemi R, Fujita S. Muscle tissue changes with aging. Curr Opin Clin Nutr Metab Care. 2004;7(4):405–10.
25. Lim S-K, Beom J, Lee SY, Kim BR, Chun S-W, Lim J-Y, Lee ES. Association between sarcopenia and fall characteristics in older adults with fragility hip fracture. Injury. 2020;51(11):2640–7.
26. Hong C, Choi S, Park M, Park SM, Lee G. Body composition and osteoporotic fracture using anthropometric prediction equations to assess muscle and fat masses. J cachexia Sarcopenia Muscle. 2021;12(6):2247–58.
27. Gkastaris K, Goulis DG, Potoupnis M, Anastasilakis AD, Kapetanos G. Obesity, osteoporosis and bone metabolism. J Musculoskelet Neuronal Interact. 2020;20(3):372.
28. Lv D, Shen S, Chen X. Association between dynapenic abdominal obesity and fall risk in older adults. Clin Interv Aging 2022:439–45.
29. Vilaca T, Evans A, Gossiel F, Paggiosi M, Eastell R, Walsh J. Fat, adipokines, bone structure and bone regulatory factors associations in obesity. Eur J Endocrinol. 2022;187(6):743–50.
30. Sunder A, Chhabra H, Aryal A. Geriatric spine fractures–demography, changing trends, challenges and special considerations: a narrative review. JCOT. 2023;43:102190.
31. Chen R, Armamento-Villareal R. Obesity and skeletal fragility. J Clin Endocrinol Metab. 2024;109(2):e466–477.
32. Hao-Wei X, Xin-Yue F, Chen H, Sheng-Jie C, Chang-Xu R, Xiao-Yong G, Shan-Jin W. The effects of abdominal obesity and sagittal imbalance on sacroiliac joint pain after lumbar fusion. Pain Physician. 2024;27(1):59.
33. Akhavanfar M, Kazemi H, Eskandari A, Arjmand N. Obesity and spinal loads; a combined MR imaging and subject-specific modeling investigation. J Biomech. 2018;70:102–12.
34. Schattner A. The wide-ranging spectrum of cough-induced complications and patient harm. Am J Med. 2020;133(5):544–51.
35. Anderson DE, Burkhart K, Alemi MM, Bouxsein ML. Chap. 16 - Biomechanics of hip and vertebral fractures. Marcus and Feldman's Osteoporosis (Fifth Edition). Volume 1. Elsevier; 2021. pp. 357–78.
36. Liang J, Chen Y, Zhang J, Ma B, Hu Y, Liu Y, Lin S, Zhang Z, Song Y. Associations of weight-adjusted body fat and fat distribution with bone mineral density in Chinese children aged 6–10 years. Int J Environ Res Public Health. 2020;17(5):1763.
37. Kirk B, Feehan J, Lombardi G, Duque G. Muscle, bone, and fat crosstalk: the biological role of myokines, osteokines, and adipokines. Curr Osteoporos Rep. 2020;18(4):388–400.
38. Zahedi H, Atayie F, Samii Kondrud F, Balali A, Beyene J, Tahery N, Asadi M, Sadeghi O. Associations of abdominal obesity with different types of bone fractures in adults: a systematic review and dose-response meta-analysis of prospective cohort studies. Crit Rev Food Sci Nutr. 2024;64(18):6239–50.
39. Donnally CJ III, DiPompeo CM, Varacallo M. Vertebral compression fractures. StatPearls [Internet]. StatPearls Publishing; 2023.
40. Ahn C, Zhang T, Yang G, Rode T, Varshney P, Ghayur SJ, Chugh OK, Jiang H, Horowitz JF. Years of endurance exercise training remodel abdominal subcutaneous adipose tissue in adults with overweight or obesity. Nat Metab 2024:1–18.

Publisher's note