RESEARCH ARTICLE

Body mass index and physical frailty among older Mexican Americans: Findings from an 18-year follow up

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Abstract

Purposes

The relationship between body mass index (BMI) and frailty in older Mexican Americans has not been previously studied. The objective of this study was to examine the relationship between BMI and frailty among non-frail older Mexican Americans at baseline over 18 years of follow up.

Methods

Longitudinal population-based study of 1,648 non-institutionalized Mexican Americans aged ≥ 67 years from the Hispanic Established Population for the Epidemiologic Study of the Elderly (1995/96-2012/13). Frailty phenotype was defined as meeting three or more of the following: unintentional weight loss of >10 pounds, weakness, self-reported exhaustion, low physical activity, and slow walking speed. BMI (kg/m^2) was classified as underweight (<18.5), normal weight (18.5-<25), overweight (25-<30), obesity category I (30-<35), and obesity category II/morbid obesity (≥35). Covariates included socio-demographics, comorbidities, cognitive function, and depressive symptoms. Generalized Estimating Equation models were performed to estimate the odds ratio (OR) and 95% confidence interval (CI) of frailty as a function of BMI category.

Results

Participants with underweight or obesity category II/morbid obesity had greater odds of frailty over time compared to those with normal weight (OR = 2.39, 95% CI = 1.29–4.44 and OR = 1.62, 95% CI = 1.07–2.44, respectively) after controlling for all covariates. Participants with BMIs in the overweight or category I obesity were at lower odds of frailty over time.
Conclusions

Mexican American older adults with BMIs in the underweight or obesity category II/morbid obesity were at higher odds of frailty over time. This indicates that maintaining a healthy weight in this population may prevent future frailty.

Introduction

Frailty is a geriatric condition characterized by decline in multiple systems leading to an impaired ability to respond to stressors [1]. It predisposes individuals to adverse events including hospitalizations, disability, cognitive decline, falls, and mortality [1–4]. There is no universally recognized definition of frailty, but the frailty phenotype described by Fried et al. is the most commonly used definition to study frailty [1]. Weight loss and low body mass index (BMI) are criteria for some definitions of frailty, including the frailty phenotype [1, 5–7]. However, studies have shown that the prevalence of frailty is higher among those malnourished, but the prevalence of malnourished is less than 10% among older adults with frailty [8–10].

The relationship between BMI and frailty has only recently been explored. Cross-sectional studies have shown that there is a U- or J-shaped relationship between BMI and frailty [6, 11–17]. Ferriolli et al. [13], using the Frailty in Brazilian Elderly (FIBRA-BR) Study, found underweight (BMI < 18.5 kg/m²) associated with frailty while obesity (BMI ≥ 30 kg/m²) was associated with prefrailty. Rietman et al. [14] using the Doetinchem Cohort Study found a high prevalence of frailty among those in the underweight (8.2%) and obesity (5.0%) categories compared with those of normal weight. Findings from the ÉPIDémiologie De I’OSTéoporose, Épidmiology of Osteoporosis (EPIDOS) Study showed a J-shaped relationship between BMI and frailty, where the percentage of underweight and obesity women who were frail was 10.8% and 20.3%, respectively [12].

Longitudinal studies have also found that obesity predicts the development of frailty [18–25]. For example, a study by Stenholm et al. [24] concluded that midlife obesity led to a fivefold increase in the risk of frailty over a 22-year follow up compared to those of normal weight among participants in the Mini-Finland Health Examination Survey. Ho et al. [19] found that older adults in the Taiwan Longitudinal Study on Aging with obesity were twice as likely to develop frailty over 8 years of follow up when compared to a group with high-normal weight. Mezuk et al. [23], examining the trajectories of BMI and incident of frailty among participants in the United States Health and Retirement Study, found that older adults with obesity and weight loss class were almost three times more likely to develop frailty over a 10-year follow-up period when compared to a group that was consistently overweight.

The older Hispanic population is one of the fastest growing ethnic groups in the United States and is projected to rise from 8% in 2018 to 21% in 2060 [26]. This population is characterized by increased risk of diabetes, obesity, and disability, all factors associated with frailty [27, 28]. Research on Mexican Americans has shown an increased risk of frailty in those with older age, female sex, impaired cognitive function, disability, pain, falls, negative affect, and diabetes [3, 4, 28–31]. Previous longitudinal studies examining the relationship between BMI and frailty included mostly non-Hispanic older adults. Therefore, the objective of this study was to examine the relationship between BMI and frailty among non-frail older Mexican Americans at baseline over 18 years of follow up. We hypothesized that Mexican Americans with BMIs in the underweight or obese ranges would have an increased risk of frailty over time compared to Mexican Americans with normal weight.
Materials and methods

Data source and study population

The data were from the Hispanic Established Populations for the Epidemiologic Study of the Elderly (EPESE). This is an ongoing longitudinal study of Mexican Americans 65 years and older who reside in Arizona, California, Colorado, New Mexico, and Texas. The original Hispanic EPESE sample consisted of 3,050 participants interviewed at baseline in 1993–1994 and followed-up every 2 or 3 years thereafter. The present study used data collected from wave 2 (1995/96) to wave 8 (2012/13), allowing for approximately 18 years of follow-up data. Information and data for the Hispanic EPESE are available at the National Archive of Computerized Data on Aging [32]. The baseline interview information was used to assess weight loss (a component of the frailty phenotype) as the difference between weight measured in 1993–94 (baseline) and weight measured in 1995–96 (wave 2). Of the 2,438 participants interviewed at wave 2 (hereafter referred as baseline), 860 were non-frail, 835 were pre-frail, and 170 were frail. We excluded the 170 participants who were frail and the 620 with missing information for any covariate, frailty measure, and BMI. The final sample included 1,648 participants aged 67 years and older. Participants excluded from the study were more likely to be older, to have a lower level of education, lower Mini-Mental State Examination (MMSE) score, and lower BMI; they also reported more strokes, heart attacks, cancer, hip fractures, and high depressive symptoms than included participants. At the end of follow up (2013), 348 participants were re-interviewed in person, 259 were lost to follow up or refused to be re-interviewed, and 1,141 were confirmed dead through the National Death Index and report from relatives (Fig 1). The University’s Institutional Review Board approved the study protocol, and oral informed consent was obtained from each participant at the time of the interview.

Measures

Predictor variable

Body mass index assessment (BMI). BMI was calculated as weight in kilograms divided by height in meters squared (kg/m$^2$). BMI was grouped according to the National Institutes of Health obesity standards: BMI < 18.5 kg/m$^2$, underweight; 18.5–24.9 kg/m$^2$, normal weight; 25–29.9 kg/m$^2$, overweight; 30–34.9 kg/m$^2$, class I obesity, and BMI $\geq$ 35 kg/m$^2$, class II/ morbid obesity [33].

Outcome variable

Modified frailty phenotype. Frailty status was determined by a modified version of the frailty phenotype defined by Fried et al. [1]. The criteria were weight loss, weakness, slowness, low physical activity, and exhaustion [1, 34]. Weight loss: $>10$ pounds, calculated as the difference between weight measured in 1993/94 and in 1995/96. Weakness: unable to perform the handgrip strength test or in the bottom 20% (adjusted for sex and BMI). Slowness: unable to perform a timed 8-foot walk test or in the bottom 20% (height-sex adjusted). Low physical activity: answered “No” to the question “Can you walk half a mile without help?” (sex-adjusted). Exhaustion: positive responses to questions from the Center for Epidemiologic Studies Depression (CES-D) Scale: “Everything I did was an effort” or “I could not get going.” Participants were classified as non-frail if they met none of the criteria, pre-frail if they met 1–2 of the criteria, and frail if they met 3 or more of the criteria. Frailty was assessed at each interview during the 18-year study period.

Covariates

Sociodemographic factors assessed were age, sex, years of formal education, and marital status (married vs. not married). Self-reported medical conditions included hypertension, arthritis,
diabetes, heart attack, stroke, cancer, and hip fracture. Cognitive function was assessed with the MMSE [35]. Depressive symptoms were measured with the CES-D Scale [36]. A score of \( \geq 16 \) was used to determine a clinical range for those with depressive symptoms [37].

**Statistical analysis**

Chi-square, Fisher’s exact, and ANOVA tests were used to describe the sample characteristics by BMI category at baseline. Generalized Estimating Equation using the GENMOD procedure in SAS was used to estimate the odds ratio (OR) and 95% confidence interval (CI) of frailty over 18 years of follow up as a function of BMI category, controlling for socio-demographics, medical conditions, cognitive function, and depressive symptoms. The models used a logit link binomial distribution and autoregressive correlation structure to account for repeated measures of participants. All variables, including BMI categories, were analyzed as time varying (potential to change over time), except for sex and education. Selection bias from missing data is minimized with the use of GEE models because it allows for the use of all available data from all follow-up interviews while accounting for differences in the follow-up duration. In estimating the working correlation parameters, all non-missing pairs of data taken from the same participants over time are used. Using the GEE procedure, we lose only the observations for which the participant is missing and not all the measurements [38–40]. Participants who died, refused to participate, or were lost to follow up were included until their last follow-up.
date (last interview date over the 18-year follow up). Additional analyses excluded those who were prefrail or frail at baseline. All analyses were performed using version 9.4 of SAS (SAS Institute, Inc., Cary, NC, USA).

Results

Table 1 shows the baseline descriptive characteristics of the overall sample and by BMI category. The mean age was 74.3 [Standard Deviation (SD) = 5.6] years and the mean BMI was 28.0 (SD = 5.1), with participants classified as 1.0% underweight, 27.4% normal weight, 39.8% overweight, 23.2% obesity category I, and 8.6% obesity category II/morbid obesity. Fifty eight percent were female, 54.9% were married, and the mean years of education was 5.0 (SD = 4.0) years. The mean MMSE score was 24.4 points (SD = 4.2). The most common medical conditions were hypertension, arthritis, and diabetes. Nine percent had high depressive symptoms. Those in the obesity category II/morbid obesity were significantly more likely to be younger (72 years), to be female (84.5%), to be unmarried (54.2%), and to report hypertension (64.1%), arthritis (62.0%), diabetes (34.5%), and high depressive symptoms (15.5%) compared to those in the underweight, normal weight, overweight or obesity category I categories. Participants in the overweight and obesity category II/morbid obesity had the highest scores on the MMSE (24.6).

Table 2 presents the results of the generalized estimating equation analysis for frailty over time as a function of BMI category. Participants in the underweight or obesity category II/morbid obesity categories had greater odds of frailty (OR = 2.40, 95% Confidence Interval (CI)
Being in overweight or obesity category did not significantly increase the odds of frailty over time. Older age, arthritis, heart attack, hip fracture, and high depressive symptoms increased the odds of frailty over time. Lower odds of frailty was also observed in those with high MMSE scores. After excluding prefrail or frail participants at baseline (N = 837), those in the underweight or obesity category II/morbid obesity categories had greater odds of frailty over time (OR = 5.09, 95% CI = 1.95–13.32 and OR = 2.80, 95% CI = 1.52–5.14, respectively) compared to those in the normal weight category, after controlling for all covariates. Those in the overweight or obesity category I group were not at increased odds of frailty over time.

Table 3 presents the results of the generalized estimating equation analysis for each frailty criterion over time as a function of BMI category. After controlling for all covariates, underweight participants had greater odds of weight loss (OR = 2.71, 95% CI = 1.71–4.28), overweight or obesity category I participants had greater odds of weakness (OR = 1.44, 95% CI = 1.20–1.71 and OR = 1.62, 95% CI = 1.31–2.01, respectively), those in obesity category I also had greater odds of exhaustion (OR = 1.1, 95% CI = 1.02–1.68), and those in the obesity category II/morbid obesity had greater odds of weakness, slowness, low physical activity, and exhaustion. Those in the overweight, obesity category I or obesity category II/morbid obesity had lower odds of weight loss over time.

Fig 2 shows the participants’ frailty status at each wave as a function of BMI category over 18-years of follow up among those who were non-frail at baseline. Frailty increased from...
Table 3. Generalized estimating equation models for each frailty criterion as a function of BMI categories over 18-years of follow up among non-frail older Mexican Americans at baseline (N = 1,648).

| BMI category       | Weight Loss OR (95% CI) | Weakness OR (95% CI) | Slowness OR (95% CI) | Low Physical Activity OR (95% CI) | Exhaustion OR (95% CI) |
|--------------------|-------------------------|---------------------|---------------------|----------------------------------|------------------------|
| Underweight        | 2.71 (1.71–4.28)        | 1.12 (0.59–2.10)    | 0.78 (0.44–1.37)    | 1.10 (0.63–1.91)                | 1.86 (0.99–3.50)      |
| Normal Weight      | Reference               | Reference           | Reference           | Reference                        | Reference              |
| Overweight         | 0.60 (0.52–0.70)        | 1.44 (1.20–1.71)    | 0.90 (0.75–1.09)    | 1.11 (0.93–1.33)                | 1.20 (0.96–1.50)      |
| Obesity Category I | 0.54 (0.45–0.64)        | 1.62 (1.31–2.01)    | 1.03 (0.82–1.29)    | 1.22 (0.99–1.51)                | 1.31 (1.02–1.68)      |
| Obesity Category II/Morbid Obesity | 0.45 (0.34–0.58) | 1.96 (1.47–2.63) | 1.42 (1.06–1.89) | 2.36 (1.80–3.10) | 1.65 (1.17–2.33) |

Note: Controlled for time (years) age (years), gender, marital status, years of education, comorbid conditions (hypertension, arthritis, diabetes, heart attack, stroke, cancer, and hip fracture), cognitive function, and depressive symptoms.

BMI = Body Mass Index; OR = odds ratio; CI = confidence interval.

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22.2% to 75% for those in the underweight category, 12.2% to 34.6% for those in the normal weight category, 8.7% to 28.8% for those in the overweight category, 6.9% to 37.5% for those in the obesity category I, and 14.9% to 83.3% for those in the obesity category II/morbid obesity.

Fig 3 presents the percent of each frailty criterion by BMI category over time among those who were non-frail at baseline. Weight loss was more prevalent among those who were in the underweight and normal weight categories during the early years of follow up and less prevalent among those who were in the obesity categories. Weakness was consistently more...
Note: BMI=Body Mass Index

Fig 3. Percent of each frailty criterion by BMI categories over time among non-frail older Mexican Americans at baseline (N = 1,648).

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Discussion

This study examined the relationship between BMI and frailty among non-frail older Mexican Americans at baseline who were followed over 18 years. This study showed a U-shaped relationship between BMI and frailty. Participants in the underweight category or obesity category II/morbid obesity were at 2 and 1.6 times, respectively, greater risk of frailty over time than those in the normal weight category, after controlling for all covariates. Results were similar after excluding pre-frail and frail participants at baseline. When we examined the relationship between BMI category and each frailty criterion, we found that underweight participants were at higher risk of weight loss, while the overweight or obese were at lower risk of weight loss. Those in the overweight or obesity categories were at higher risk for weakness, slowness, exhaustion, and low physical activity.

Our findings are similar to those from previous cross-sectional [6, 11–16] and longitudinal [18–25] studies that demonstrated a U-or J-shaped relationship between BMI and frailty. Gajic-Veljanoski et al. [41], using the Canadian Multi-Centre Osteoporosis Study, found that baseline BMIs $\geq 25 \text{kg/m}^2$ was associated with faster frailty progression over 5-years with the greatest effect among those with $\text{BMI} \geq 40 \text{kg/m}^2$ when compared to those with normal weight. Landré et al. [21] examined the relationship between weight history during adulthood and frailty among participants from the GAZEL (GAZ and ELectricité) Cohort and found that long term obesity and onset of obesity in late adulthood were associated with frailty over 25 years of follow up when compared with those with normal weight. In another study, Strandberg et al. [25] used the Helsinki Businessmen Study to determine whether midlife obesity could be a predictor of frailty over a 26-year follow up among the initially healthy. They found that those who were overweight or obese in midlife were twice as likely to develop frailty compared to those of normal weight. The studies of Landré [21] and Strandberg [25] considered normal weight as BMIs $< 25 \text{kg/m}^2$. A recent systematic review and meta-analysis conducted by Yuan et al. [42] found that underweight and obesity both increased the risk of frailty over time.

Some mechanisms can explain our findings. The increased risk of frailty over time among those in the underweight category may be related to the weight loss criterion for frailty used in our study; however, weight loss can be seen in any of the BMI categories, not just in those who are underweight. Another explanation is the loss of muscle mass seen in older adults with undernutrition which is accompanied by low BMI [43, 44]. The increased risk of frailty over time among those in the obesity category II/morbid obesity may be related to the association of obesity with multiple conditions like insulin resistance, diabetes, cardiovascular disease, and increased inflammation, all of which are risk factors for frailty [45, 46]. Another explanation is related to the decreased muscle mass seen in older adults with obesity, known as “sarcopenia obesity”[47, 48].

Our study has some limitations. First, comorbid conditions were assessed through self-reports. This may lead to recall bias as compared to physician assessment. Second, participants excluded from the study were less healthy than those included, which might have led to underestimating the relationship between BMI and frailty. Third, participants who died before wave
2 may have produced a survival bias. Fourth, we do not have the measure of waist circumference (WC) assessed in all study waves. In older adults, WC has been suggested to be a better predictor than weight alone of whole-body fat percent and visceral adipose tissue [49, 50]. Fifth, our measure of frailty phenotype does not consider cognitive function or psychosocial measures [51]. Finally, our findings are not generalizable to the larger Hispanic population in the United States. This study has several strengths, including its large community-based sample of older Mexican Americans, a disadvantaged and underserved population, the length of follow up, and the use of generalized estimating equation models, an analytical approach that allows using all available data on socio-demographics, comorbidities, and BMI as time varying.

Conclusions
This study shows that older Mexican Americans in the underweight or obesity type II/morbid obesity categories are at increased risk of frailty over an 18-year follow up when compared to those of normal weight. Overweight or obese older Mexican Americans were at higher risk of weakness, slowness, exhaustion, and low physical activity. Interventions should be implemented to improve body weight among the underweight and morbid obesity to enhance physical function, increase muscle strength, and increase levels of physical activity to prevent prefrailty or frailty in this population.

Author Contributions
Conceptualization: Megan Rutherford, Brian Downer, Chih-Ying Li, Lin-Na Chou, Soham Al Snih.
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Visualization: Megan Rutherford.
Writing – original draft: Megan Rutherford.
Writing – review & editing: Megan Rutherford, Brian Downer, Chih-Ying Li, Lin-Na Chou, Soham Al Snih.

References
1. Fried LP, Tangen CM, Walston J, Newman AB, Hirsch C, Gottdiener J, et al. Frailty in older adults: evidence for a phenotype. J Gerontol A Biol Sci Med Sci. 2001; 56(3):M146–56. https://doi.org/10.1093/gerona/56.3.m146 PMID: 11259156
2. Graham JE, Snih SA, Berges IM, Ray LA, Markides KS, Ottenbacher KJ. Frailty and 10-year mortality in community-living Mexican American older adults. Gerontology. 2009; 55(6):644–51. https://doi.org/10.1159/000235653 PMID: 19690395
3. Samper-Ternent R, Al Snih S, Raji MA, Markides KS, Ottenbacher KJ. Relationship between frailty and cognitive decline in older Mexican Americans. J Am Geriatr Soc. 2008; 56(10):1845–52. https://doi.org/10.1111/j.1532-5415.2008.01947.x PMID: 18811611
4. Samper-Ternent R, Karmarkar A, Graham J, Reistetter T, Ottenbacher K. Frailty as a predictor of falls in older Mexican Americans. Journal of aging and health. 2012; 24(4):641–53. https://doi.org/10.1177/0898264311428490 PMID: 22187090

5. Bandeen-Roche K, Xue QL, Ferrucci L, Walston J, Guralnik JM, Chaves P, et al. Phenotype of frailty: characterization in the women’s health and aging studies. J Gerontol A Biol Sci Med Sci. 2006; 61(3):282–6. https://doi.org/10.1093/gerona/61.3.262 PMID: 16567375

6. Hubbard RE, Lang IA, Llewellyn DJ, Rockwood K. Frailty, body mass index, and abdominal obesity in older people. J Gerontol A Biol Sci Med Sci. 2010; 65(4):377–81. https://doi.org/10.1093/gerona/glp186 PMID: 19942592

7. Topinkova E. Aging, disability and frailty. Ann Nutr Metab. 2008; 52 Suppl 1:6–11. https://doi.org/10.1159/000115340 PMID: 18382070

8. Morley JE. Weight loss in older persons: new therapeutic approaches. Curr Pharm Des. 2007; 13(36):3637–47. https://doi.org/10.2174/138161207782794149 PMID: 18220800

9. Wei K, Nyunt MSZ, Gao Q, Wee SL, Ng TP. Frailty and Malnutrition: Related and Distinct Syndrome Prevalence and Association among Community-Dwelling Older Adults: Singapore Longitudinal Ageing Studies. J Am Med Dir Assoc. 2017; 18(12):1019–28. https://doi.org/10.1016/j.jamda.2017.06.017 PMID: 28804010

10. Verlaan S, Ligthart-Melis GC, Wijers SLJ, Cederholm T, Maier AB, de van der Schueren MAE. High Prevalence of Physical Frailty Among Community-Dwelling Malnourished Older Adults: A Systematic Review and Meta-Analysis. J Am Med Dir Assoc. 2017; 18(5):374–82. https://doi.org/10.1016/j.jamda.2016.12.074 PMID: 28238676

11. Blaum CS, Xue QL, Michelon E, Semba RD, Fried LP. The association between obesity and the frailty syndrome in older women: the Women’s Health and Aging Studies. J Am Geriatr Soc. 2005; 53(6):927–34. https://doi.org/10.1111/j.1532-5415.2005.53300.x PMID: 15935013

12. Boutin E, Natella PA, Schott AM, Bastuji-Garin S, David JP, Paillaud E, et al. Interrelations between body mass index, frailty, and clinical adverse events in older community-dwelling women: The EPIDOS cohort study. Clin Nutr. 2018; 37(5):1638–44. https://doi.org/10.1016/j.clnu.2017.07.023 PMID: 28844302

13. Ferriolli E, Pessanha F, Moreira VG, Dias RC, Neri AL, Lourenco RA. Body composition and frailty profiles in Brazilian older people: Frailty in Brazilian Older People Study-FIBRA-BR. Arch Gerontol Geriatr. 2017; 71:99–104. https://doi.org/10.1016/j.archger.2017.03.005 PMID: 28395196

14. Rietman ML, van der AD, van Oostrom SH, Picavet HSJ, Dolle MET, van Steeg H, et al. The Association between BMI and Different Frailty Domains: A U-Shaped Curve? J Nutr Health Aging. 2018; 22(1):8–15. https://doi.org/10.1007/s12603-016-0854-3 PMID: 29300416

15. Watanabe D, Yoshida T, Watanabe Y, Yamada Y, Kimura M, Kyoto-Kameoka Study Group. A U-Shaped Relationship Between the Prevalence of Frailty and Body Mass Index in Community-Dwelling Japanese Older Adults: The Kyoto-Kameoka Study. J Clin Med. 2020;9(5). https://doi.org/10.3390/jcm9051367 PMID: 32384756

16. Woods NF, LaCroix AZ, Gray SL, Aragaki A, Cochrane BB, Brunner RL, et al. Frailty: emergence and consequences in women aged 65 and older in the Women’s Health Initiative Observational Study. J Am Geriatr Soc. 2005; 53(8):1321–30. https://doi.org/10.1111/j.1532-5415.2005.53405.x PMID: 16078957

17. Xu IZ, Shen S, Hong X, Zeng X, Yang Y, Liu Z, et al. Association between body composition and frailty in elderly inpatients. Clinical Interventions in Aging. 2020; 15:8. https://doi.org/10.2147/CIA.S243211 PMID: 32184580

18. Garcia-Esquinas E, Jose Garcia-Garcia F, Leon-Munoz LM, Carnicer JA, Guallar-Castillon P, Gonzalez-Colaco Harmand M, et al. Obesity, fat distribution, and risk of frailty in two population-based cohorts of older adults in Spain. Obesity (Silver Spring). 2015;23(4):847–55.

19. Ho HE, Yeh CJ, Chu WM, Lee MC. Midlife Body Mass Index Trajectory and Risk of Frailty 8 Years Later in Taiwan. J Nutr Health Aging. 2019; 23(9):849–55. https://doi.org/10.1007/s12603-019-1226-6 PMID: 31641735

20. Kim M, Lee Y, Kim EY, Park Y. Mediating effect of waist:height ratio on the association between BMI and frailty: the Korean Frailty and Aging Cohort Study. Br J Nutr. 2020; 124(5):513–20. https://doi.org/10.1017/S0007114519002098 PMID: 31452484

21. Landre B, Czernichow S, Goldberg M, Zins M, Ankri J, Herr M. Association Between Life-Course Obesity and Frailty in Older Adults: Findings in the GAZEL Cohort. Obesity (Silver Spring). 2020; 28(2):388–96. https://doi.org/10.1002/oby.22682 PMID: 31970909

22. Liao Q, Zheng Z, Xiu S, Chan P. Waist circumference is a better predictor of risk for frailty than BMI in the community-dwelling elderly in Beijing. Aging Clin Exp Res. 2018; 30(11):1319–25. https://doi.org/10.1007/s40520-018-0933-x PMID: 29589287
23. Mezuk B, Lohman MC, Rock AK, Payne ME. Trajectories of body mass indices and development of frailty: Evidence from the health and retirement study. Obesity (Silver Spring). 2016; 24(8):1643–7. https://doi.org/10.1002/oby.21572 PMID: 27355440

24. Stenholm S, Strandberg TE, Pitkala K, Sainio P, Heliovaara M, Koskinen S. Midlife obesity and risk of frailty in old age during a 22-year follow-up in men and women: the Mini-Finland Follow-up Survey. J Gerontol A Biol Sci Med Sci. 2014; 69(1):73–8. https://doi.org/10.1093/gerona/glt052 PMID: 23640762

25. Strandberg TE, Sirola J, Pitkala KH, Tilvis RS, Strandberg AY, Stenholm S. Association of midlife obesity and cardiovascular risk with old age frailty: a 26-year follow-up of initially healthy men. Int J Obes (Lond). 2012; 36(9):1153–7. https://doi.org/10.1038/ijo.2012.83 PMID: 22614054

26. Federal Interagency Forum on Aging-Related Statistics. Older Americans 2020: Key indicators of well-being. Washington, DC: U.S. Government Printing Office.

27. Flegal KM, Kruszon-Moran D, Carroll MD, Fryar CD, Ogden CL. Trends in Obesity Among Adults in the United States, 2005 to 2014. JAMA. 2016; 315(21):2284–91. https://doi.org/10.1001/jama.2016.6458 PMID: 27272580

28. Ottenbacher KJ, Graham JE, Al Snih S, Raji M, Samper-Tenent R, Ostrin GV, et al. Mexican Americans and frailty: findings from the Hispanic established populations epidemiologic studies of the elderly. Am J Public Health. 2009; 99(4):673–9. https://doi.org/10.2105/AJPH.2008.143958 PMID: 19197079

29. Al Snih S, Graham JE, Ray LA, Samper-Tenent R, Markides KS, Ottenbacher KJ. Frailty and incidence of activities of daily living disability among older Mexican Americans. J Rehabil Med. 2009; 41(11):892–7. https://doi.org/10.2340/16501977-0424 PMID: 19841840

30. Howrey BT, Al Snih S, Markides KS, Ottenbacher KJ. Frailty and diabetes among older Mexican Americans. J Am Geriatr Soc. 2009; 57(12):2393–7. https://doi.org/10.1111/j.1532-5415.2009.02742.x PMID: 19978652

31. Ostrin GV, Ottenbacher KJ, Markides KS. Onset of frailty in older adults and the protective role of positive affect. Psychol Aging. 2004; 19(3):402–8. https://doi.org/10.1037/0882-7977.19.3.402 PMID: 15382991

32. Markides KS, Angel R, Palmer R. Hispanic Established Populations for the Epidemiologic Study of the Elderly (HEPESE) Wave 8, 2012–2013 [Arizona, California, Colorado, New Mexico, and Texas]. Natl Arch Comput Data Aging.; 2016.

33. National Heart, Lung, and Blood Institute. Obesity Education Initiative: The Evidence Report. Bethesda, MD; 1998. http://www.nhlbi.nih.gov/health/public/heart/obesity/lose_wt/bmi_dis.htm

34. Li CY, Al Snih S, Chen NW, Markides KS, Sodhi J, Ottenbacher KJ. Validation of the Modified Frailty Phenotype Measure in Older Mexican Americans. J Am Geriatr Soc. 2019; 67(11):2393–7. https://doi.org/10.1111/jgs.16104 PMID: 31414494

35. Folstein MF, Folstein SE, McHugh PR. “Mini-mental state”. A practical method for grading the cognitive state of patients for the clinician. J Psychiatr Res. 1975; 12(3):189–98.

36. Radloff LS. The CES-D scale: A self-report depression scale for research in the general population. Applied Psychological Measurement 1977; 1:385–401.

37. Boyd JH, Weissman MM, Thompson WD, Myers JK. Screening for depression in a community sample. Understanding the discrepancies between depression symptom and diagnostic scales. Arch Gen Psychiatry. 1982; 39(10):1195–200. https://doi.org/10.1001/archpsyc.1982.04290100059010 PMID: 7125849

38. Liang KY, Zeger SL. Longitudinal data analysis using generalized linear models. Biometrika. 1986: 10.

39. Wedderburn RWM. Quasi-Likelihood Functions, Generalized Linear Models, and the Gauss-Newton Method. Biometrika. 1974; 61 (3): 439–47.

40. Zeger SL, Liang KY. Longitudinal data analysis for discrete and continuous outcomes. Biometrics. 1986; 42(1):121–30. PMID: 3719049

41. Gajic-Veljanoski O, Papaioannou A, Kennedy C, Ioannidis G, Berger C, Wong AKO, et al. Osteoporotic fractures and obesity affect frailty progression: a longitudinal analysis of the Canadian multicentre osteoporosis study. BMC Geriatr. 2018; 18(1):4. https://doi.org/10.1186/s12877-017-0692-0 PMID: 29304836

42. Yuan L, Chang M, Wang J. Abdominal obesity, body mass index and the risk of frailty in community-dwelling older adults: a systematic review and meta-analysis. Age Ageing. 2021; 50(4):1118–28. https://doi.org/10.1093/ageing/afab039 PMID: 33693472

43. Falsarella GR, Gasparotto LP, Barcelos CC, Coimbra IB, Moretto MC, Pascoa MA, et al. Body composition as a frailty marker for the elderly community. Clin Interv Aging. 2015; 10:1661–6. https://doi.org/10.2147/CIA.S84632 PMID: 26527868
44. Reinders I VM, Schaap L. Body weight and body composition in old age and their relationship with frailty. Curr Opin Clin Nutr Metab Care. 2017; 5. https://doi.org/10.1097/MCO.0000000000000332 PMID: 27749713

45. Clegg A, Young J, Iliffe S, Rikkert MO, Rockwood K. Frailty in elderly people. Lancet. 2013; 381 (9868):752–62. https://doi.org/10.1016/S0140-6736(12)62167-9 PMID: 23395245

46. Hoogendijk EO, Afilalo J, Ensrud KE, Kowal P, Onder G, Fried LP. Frailty: implications for clinical practice and public health. Lancet. 2019; 394(10206):1365–75. https://doi.org/10.1016/S0140-6736(19)31786-6 PMID: 31609228

47. Batsis JA, Villareal DT. Sarcopenic obesity in older adults: aetiology, epidemiology and treatment strategies. Nat Rev Endocrinol. 2018; 14(9):513–37. https://doi.org/10.1038/s41574-018-0062-9 PMID: 30065268

48. Remelli F, Maietti E, Abete P, Bellelli G, Bo M, Cherubini A, et al. Prevalence of obesity and diabetes in older people with sarcopenia defined according to EWGSOP2 and FNHI criteria. Aging Clin Exp Res. 2022; 34(1):113–20. https://doi.org/10.1007/s40520-021-01949-1 PMID: 34398439

49. Ross R, Neeland IJ, Yamashita S, Shai I, Seidell J, Magni P, et al. Waist circumference as a vital sign in clinical practice: a Consensus Statement from the IAS and ICCR Working Group on Visceral Obesity. Nat Rev Endocrinol. 2020; 16(3):177–89. https://doi.org/10.1038/s41574-019-0310-7 PMID: 32020062

50. Swainson MG, Batterham AM, Tsakirides C, Rutherford ZH, Hind K. Prediction of whole-body fat percentage and visceral adipose tissue mass from five anthropometric variables. PLoS One. 2017; 12(5): e0177175. https://doi.org/10.1371/journal.pone.0177175 PMID: 28493988

51. Abete P, Basile C, Bulli G, Curcio F, Liguori I, Della-Morte D, et al. The Italian version of the "frailty index" based on deficits in health: a validation study. Aging Clin Exp Res. 2017; 29(5):913–26. https://doi.org/10.1007/s40520-017-0793-9 PMID: 28688080