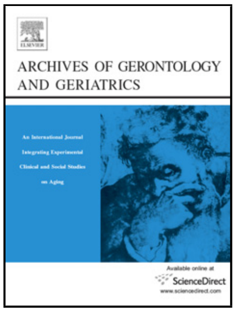

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Associations of components of sarcopenic obesity with bone health and balance in older adults

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Abstract

Objectives: To determine characteristics of sarcopenic obesity that are independently associated with bone health and balance in older adults.

Study design: Cross-sectional study of 168 community-dwelling older adults (mean age 67.7±8.4 years; 55% women).

Main outcome measures: Appendicular lean mass (ALM), whole-body areal BMD (aBMD) and body fat percentage were assessed by dual-energy X-ray absorptiometry. Peripheral quantitative computed tomography assessed muscle density and cortical volumetric BMD (vBMD), area, thickness, and strength-strain index (SSI) at 66% tibial length. Hand grip strength (dynamometry) and balance path length (computerised posturography) were assessed. Obesity was defined as high body fat percentage.

Results: Greater lower-leg muscle density was associated with lower balance path length in men (r=-0.36; P<0.01) and women (r=-0.40; P=<0.01). Obese participants by body fat percentage did not differ to non-obese on bone indices, although a trend towards lower cortical vBMD was observed in obese compared with non-obese men (1041.4±39.8 vs 1058.8±36.1 mg/cm^3; P=0.051). In multivariable models, ALM was positively associated with all bone parameters in obese women, and with whole-body aBMD, proximal tibial cortical area and SSI in non-obese women, and both non-obese and obese men (all P<0.05). Lower-leg muscle density was also positively associated with cortical vBMD (B=2.91; 95% CI 0.02, 5.80) and area (2.70; 0.06, 5.33) in obese women.

Conclusions: Amongst components of sarcopenic obesity, higher ALM is a consistent independent predictor of better bone health. Low muscle density may also compromise bone health and balance. Interventions which improve muscle mass and composition may lower fracture risk in sarcopenic obesity.

Keywords: sarcopenic obesity; muscle density; bone; osteoporosis; balance; muscle strength

1.0 Introduction

Obese older adults with sarcopenia (inadequate skeletal muscle mass and function), may have increased risk for function declines (1). We recently demonstrated that obesity combined with sarcopenia defined by the Foundation for the National Institutes of Health (FNIH) criteria (2), is associated with increased fracture risk relative to obesity alone, but not an increased rate of falls (3). This suggests that increased fracture risk in sarcopenic obesity is related to poorer bone strength. Sarcopenic obese older adults have lower areal bone mineral density (aBMD) than obese alone older adults (4-6). However, other measures of bone health, such as volumetric BMD (vBMD) and bone geometry, contribute to fracture risk independently of aBMD (7). Studies are required to determine whether sarcopenic obesity influences bone health in older adults, and which individual components are most important.

Age-related decreases in lower-limb muscle density, indicative of increases in fat infiltration between muscle fibres and within muscle cells (8), are associated with functional decline and increased risk of falls (9, 10) and fractures (11) in older adults. Low muscle density may be more prevalent in sarcopenic obesity (12), potentially contributing to increased falls and fracture risk in this population. The aim of the present study was to determine the independent associations that components of sarcopenic obesity have with bone health and balance in community-dwelling older adults.

2.0 Materials and Methods

2.1 Study design and participants

One-hundred and seventy-three community-dwelling adults aged ≥50 years residing in Melbourne, Australia who responded to advertisements at local hospitals, general practices, community groups, and sporting and recreation clubs, were recruited for this study. Participants were English speaking, capable of walking across a room unaided, and had no self-reported diagnosis of progressive neurological or psychotic disorders, severe arthritis (awaiting a joint replacement), or life expectancy <12 months. The study was approved by the Melbourne Health Human Research Ethics Committee (HREC 2013.079 and HREC 2013.294) and was carried out in accordance with The Code of Ethics of the World Medical Association (Declaration of Helsinki). All participants provided written informed consent.

All testing was conducted at the Clinical Trials Unit at the Australian Institute for Musculoskeletal Science (AIMSS) between March 2014 and August 2016. Participants provided a fasted blood sample at the hospital pathology centre. Serum glucose, total and high-density lipoprotein (HDL) cholesterol, and triglycerides concentrations were analysed using the automated ADVIA 1650 Chemistry System (Siemens Healthcare Diagnostics Incorporation, Australia). The DiaSorin LIAISON (DiaSorin Inc, Stillwater, MN, USA) chemiluminescent immunoassay measured serum 25-hydroxyvitamin D (25OHD) concentrations.

A self-administered questionnaire including questions on employment status and chronic health conditions including cardiovascular disease (coronary heart disease and/or hypertension), diabetes and osteoporosis was completed. Self-rated health was also assessed by response to the question "Would you say that in general your health is:" with possible responses of: excellent; very good; good; fair; poor. Total minutes of weekly physical activity was assessed by the Active Australia Survey (13).

2.2 Anthropometrics, body composition and bone parameters

Weight (Seca 804 electronic scales, Seca, Hamburg, Germany) and height (Seca 222 wall-mounted stadiometer, Seca, Hamburg, Germany) were measured with footwear, headwear, and heavy items of clothing removed. Body mass index (BMI) was calculated as weight (kg)/ height (m^2) and obesity was defined as BMI ≥30kg/m^2.

A whole-body DXA (Hologic Discovery W, Hologic, Bedford MA, USA) determined whole-body (minus head) aBMD and total body fat, and regional lean and fat mass, including appendicular lean mass (ALM) and visceral fat area. Obesity according to body fat percentage was defined as total body fat percentage ≥30% for men or ≥40% for women (14). The DXA was calibrated daily using the manufacturer's phantom. Short-term inter-individual coefficients of variation (CV) for whole-body BMD and ALM in our laboratory were 1.5 and 1.0%, respectively.

A single 2.5-mm transverse peripheral quantitative computed tomography (pQCT; Stratec XCT3000, Stratec Medizintechnik GmbH, Pforzheim, Germany) scan with a voxel size of 0.8mm and scan speed of 20mm/sec was obtained at 66% of tibial length of the dominant leg, measured proximally beginning from the tibiotarsal joint. The dominant leg was preferentially selected for this assessment to allow comparability of muscle composition measures with strength assessments performed in the same limb (not included in the present study). Lower-leg muscle cross-sectional area (CSA; mm^2) and density (mg/cm^3) were determined using manufacturer's algorithms and software (version 6.2). A threshold of 40 mg/cm^3 (mid-point density between fat and muscle tissue) separated fat and muscle. The short-term CV for muscle density in our hands was 1.0% (15). The default threshold of 710mg/cm^3 was used to separate cortical bone (16). Proximal tibial cortical vBMD (mg/cm^3), area (mm^2) and thickness (average distance between periosteal and endosteal circumferences;

mm) were recorded. Polar strength-strain index (SSI) was calculated with a threshold of 280mg/cm^3 (17). The device was calibrated daily using the manufacturer's phantom. The CV for phantom density was 0.2% for the duration of the study.

2.3 Physical function

Dominant hand grip strength was assessed using a Jamar Plus Digital hydraulic hand grip dynamometer (Patterson Medical, Bolingbrook, IL, USA). Participants were seated with their elbow fully extended in front of them at shoulder height and gripped the dynamometer with maximal force for three seconds. The test was completed three times with a 30-second rest between trials and the mean value was recorded.

Balance path length (total distance travelled by the centre of pressure) was assessed during a bipedal standing balance task using a Nintendo Wii Balance Board (RVL-021; Nintendo, Kyoto, Japan) and custom software. The test measures movements in centre of pressure with acceptable reliability and validity compared to a laboratory-grade force platform (18, 19). Participants were required to stand with feet apart and eyes open for 30-seconds. Mean values from two trials with 30 second inter-trial rest periods were calculated. Higher path length values indicated poorer balance.

2.4 Statistical analyses

Continuous data were assessed for normality using Shapiro-Wilk tests and non-normally distributed variables were analysed using non-parametric tests. Sarcopenia was defined using the FNIH definition (ALM relative to BMI <0.789 (men) or <0.512 (women) and hand grip strength <26kg (men) or <16kg (women) (2). Independent samples t-tests, Mann-Whitney U tests or Chi-square tests compared descriptive characteristics between men and women as appropriate. Sex-stratified Pearson correlations explored associations between components of sarcopenic obesity (ALM, hand grip strength, total body fat percentage and lower-leg muscle density), bone indices (whole-body aBMD, and proximal tibial cortical vBMD, area, thickness and SSI) and balance path length. Independent samples t-tests compared bone indices between obese and non-obese men and women according to both BMI and body fat percentage. Multivariable linear regression models adjusted for age and sex explored associations between sarcopenic obesity components and bone indices. These analyses were also adjusted for fasting blood glucose given that type 2 diabetes may be associated with both sarcopenic obesity and poor bone health. In order to explore independent associations of sarcopenic obesity components with bone health, each component was included in all models. Plots of residuals against the predictor variable were used to test assumptions of normality of residuals and homoscedasticity, and Variance Inflation Factors were examined to confirm the absence of multicollinearity between independent variables included in these models. P-values <0.05 or 95% confidence intervals (CI) not including the null point were considered statistically significant. All analyses were performed in SPSS Statistics 22 (IBM, USA).

3.0 Results

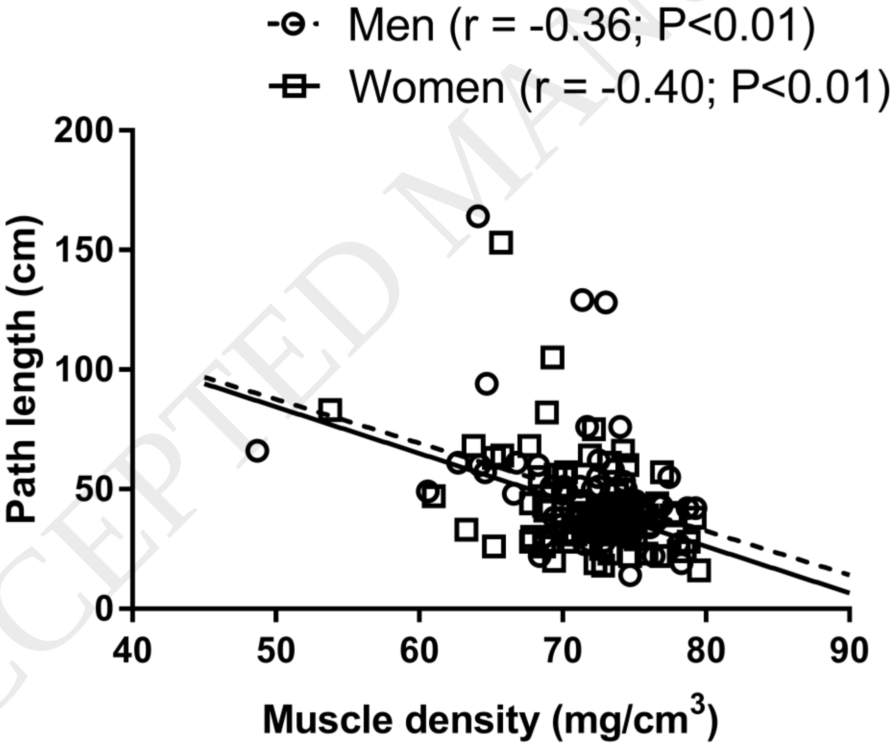
Of 173 recruited participants, four could not have BMD estimated due to arthroplasties and one could not perform the hand grip strength assessment due to rheumatoid arthritis, resulting in 168 participants being included. Amongst included participants (mean age 67.7±8.4 years; 55% women), 34 (20%) had low lean mass and 16 (10%) had low hand grip strength according to the FNIH definition of sarcopenia. Descriptive characteristics, with comparisons between men and women, are presented in Table 1. A higher proportion of women than men reported osteoporosis, and total cholesterol levels were also higher in women. Women reported lower levels of physical activity and had lower ALM, lower-leg muscle cross-sectional area, hand grip strength, whole-body aBMD, and proximal tibial cortical vBMD than men, but there were no differences between sexes for lower-leg muscle density.

Table 2 presents Pearson correlations examining relationships between components of sarcopenic obesity and bone parameters in men. ALM was positively correlated with whole-body aBMD, proximal tibial cortical area and thickness. Hand grip strength was also positively correlated with cortical area. BMI was positively correlated with whole-body aBMD but total body fat percentage was not associated with bone parameters. Lower-leg muscle density was positively correlated with cortical vBMD in men.

Table 3 presents Pearson correlations examining relationships between components of sarcopenic obesity and bone parameters in women. ALM, BMI and hand grip strength were both positively correlated with all proximal tibial bone parameters, and ALM and BMI were additionally positively correlated with whole-body aBMD. Body fat percentage, but not lower-leg muscle density, was positively correlated with proximal tibial cortical vBMD and thickness in women.

Pearson correlations also compared associations between components of sarcopenic obesity and balance path length. ALM, hand grip strength and total body fat percentage were not correlated with path length (all P>0.05). However, as demonstrated in Figure 1, weak negative correlations between muscle density and path length were observed in both sexes. Several outliers were observed for these correlations but after excluding participants with path length ≥100 cm and with lower-leg muscle density <60mg/cm^3, the correlations remained significant in men (r=-0.41; P<0.01) and women (r=-0.29; P<0.01).

Figure 1. Pearson correlations for muscle density and balance test path length in men and women



Forty-seven and 53% of participants were obese according to BMI and body fat percentage cut-points, respectively. A higher proportion of obese compared with non-obese participants had low lean mass (BMI: 37 vs 5%; body fat percentage: 33 vs 5%; both

$P<0.001$). A lower proportion of obese participants according to BMI (4 vs 15%; $P=0.017$), but not body fat percentage (9 vs 10%; $P=0.763$), had low hand grip strength. Obese participants had reduced lower-leg muscle density (BMI: 70.9±3.8 vs 72.9±4.5 mg/cm^3; body fat percentage: 71.1±4.7 vs 72.9±3.6 mg/cm^3; both $P\leq0.005$). Figure 2 presents means for bone parameters according to obesity status. Participants who were obese according to BMI, but not body fat percentage, had significantly greater whole-body aBMD than non-obese. Similarly, tibial cortical area and thickness in women only, and SSI in both sexes, was significantly higher for obese participants according to BMI. There were no differences in tibial bone parameters for obese and non-obese participants defined by body fat percentage, although borderline significant higher tibial cortical vBMD was observed for non-obese compared with obese men ($P=0.051$).

Figure 2. Sex-stratified differences (mean ± SD) in bone parameters between non-obese and obese participants according to BMI and total body fat percentage (BF%).

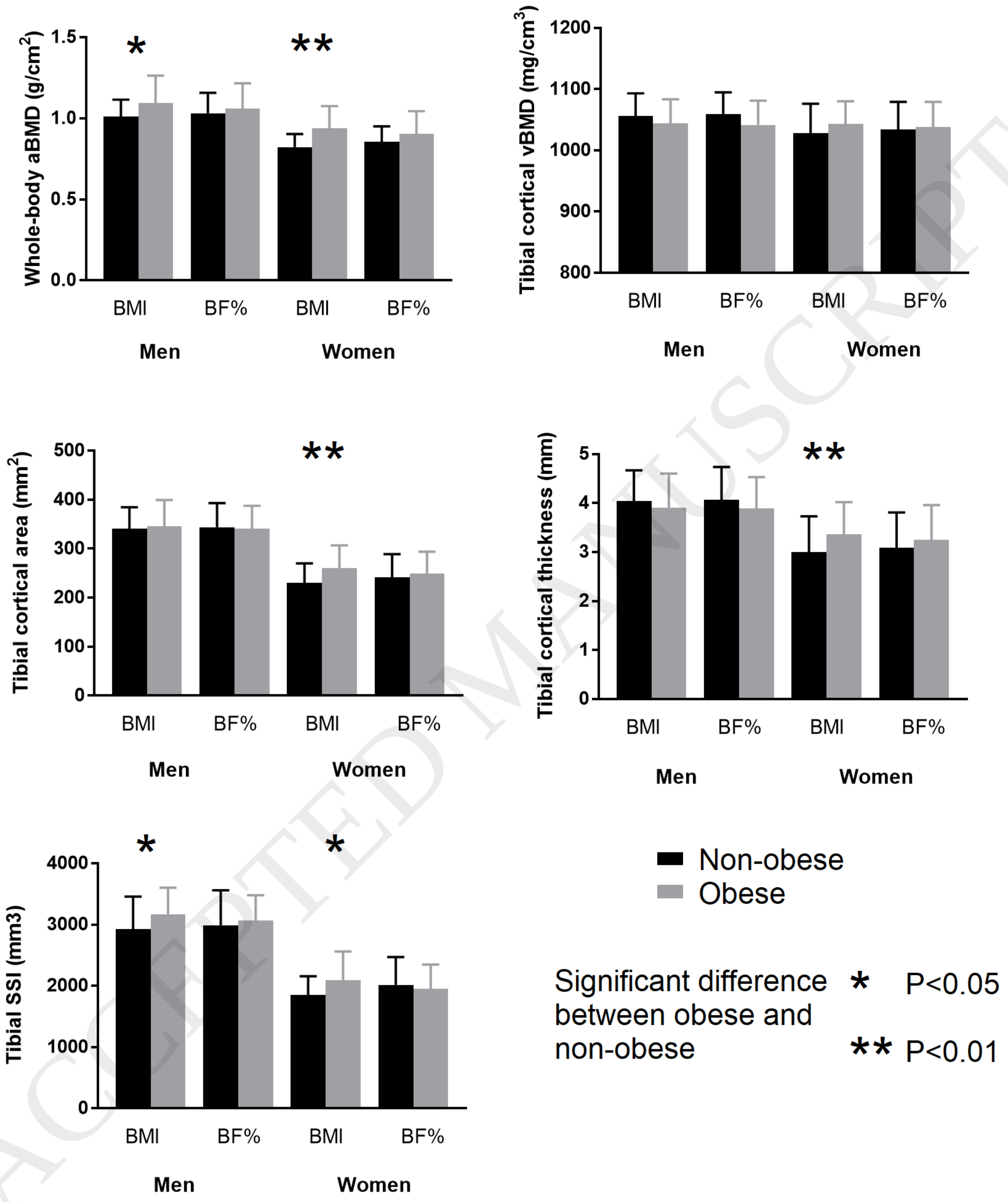


Table 4 presents coefficients from multivariable linear regression models examining associations of components of sarcopenic obesity with bone parameters for non-obese and obese men and women. In non-obese men and women, and also obese men, ALM was positively associated with whole-body aBMD and proximal tibia cortical area and SSI. Lower-leg muscle density was negatively associated with cortical area in non-obese men but positively associated with cortical area and cortical vBMD in obese women. There was also a trend for higher cortical thickness with increasing muscle density ($P<0.06$), and ALM was positively associated with all bone parameters, in obese women. Neither hand grip strength nor total body fat percentage were associated with bone parameters in multivariable models. However, negative trends for body fat percentage with proximal tibia SSI ($P=0.08$) and cortical area ($P=0.07$) were observed in obese women and obese men, respectively.

.4.0 Discussion

This cross-sectional study of community-dwelling older adults demonstrated that, amongst components of sarcopenic obesity, higher ALM was most consistently associated with better bone health. Lower-leg muscle density was associated with higher proximal tibial cortical vBMD and area in obese women, and was the only component of sarcopenic obesity negatively correlated with postural sway. These findings suggest that increased fracture risk in sarcopenic obesity is likely explained by poor muscle mass and quality, which may lead to reduced bone strength and balance.

We previously reported sarcopenic obese older adults have increased risk of incident fractures, but not falls, compared with obese alone (3, 4). This suggested that increased fracture risk was related to poorer bone health in sarcopenic obesity and areal BMD has been demonstrated to be lower in sarcopenic obese compared with obese alone older adults in several studies (3-6, 20). The present study explored associations of multiple sarcopenic obesity components with pQCT-derived tibial bone parameters. ALM was most consistently associated with these outcomes and this is supported by results from the Hertfordshire Cohort Study demonstrating that lean mass, not fat mass, index was positively associated with distal tibial cortical area and thickness in older adults (21). Although hand grip strength was positively correlated with bone parameters in our study, these associations were not significant after adjustment for other components of sarcopenic obesity. A previous study of men and women aged 50 years and older also reported that hand grip strength is not related to distal radius bone strength after adjustment for body size (22). This suggests that the relationship of muscle strength with bone health in older adults is mediated by muscle mass.

Interestingly, we observed that lower-leg muscle density was positively associated with proximal tibial cortical vBMD and area, and had a borderline significant positive association with cortical thickness, in obese women. A recent study of 178 osteoporotic women with hip fractures similarly demonstrated that gluteus maximus and abductor muscle density was positively associated with hip BMD (23). A study by Lorbergs et al., reported that high relative lower-limb intra-muscular fat (assessed by magnetic resonance imaging) was associated with pQCT-derived tibial bone content and area (24) in healthy older women. Fat infiltration of muscle may have negative effects on local bone health through increases in lipotoxicity and local inflammation (25), and it is possible that interventions that reduce fat infiltration may improve bone strength in older women in particular.

Amongst components of sarcopenic obesity, only greater lower-leg muscle density was negatively correlated with balance path length. This suggests lower muscle density contributes to the association between high body mass and poor balance (26), and a previous study of 174 osteopenic men and women aged over 60 years also demonstrated that higher trunk muscle density was associated with reduced postural sway (27). It is likely that increased postural sway at least in part explains the increased likelihood of falls in those with lower muscle density. Retrospective studies have reported that lower-leg muscle density is around 2 mg/cm^3 lower in older women with one or more past 12-month falls (9), and that likelihood of falls is reduced by almost 20% for every 1 mg/cm3 increase in lower leg muscle density (10). These associations may also be consistent across a range of lower-limb muscle groups, with older adult fallers demonstrating lower muscle density for the psoas, gluteus maximus and minimus, vastus lateralis, and adductors (28). It is therefore possible that reduced muscle density of the lower limbs increases risk of fractures through both decreases in bone strength and increases in falls. Indeed, low thigh muscle density was independently associated with a two-fold increase in 6-year hip fracture incidence in 3,075 US older adults aged 70-79 years (11).

Men and women with high BMI had greater whole-body aBMD and proximal tibial SSI, and women with high BMI also had greater cortical area and thickness, than those with low BMI. There were no differences in bone parameters for participants with high versus low body fat percentages, although a trend towards lower tibial cortical vBMD was observed for obese men. These results are supportive of previous research indicating that higher lean mass, not fat mass, explains greater bone size and strength in obese individuals (29). The use of BMI estimates to determine fracture risk may therefore be inappropriate, but this likely occurs in the clinic. Older women who are obese according to BMI are significantly less likely to receive bone protective medications and undergo DXA than non-obese (30, 31). Assessments of body composition, particularly ratios of lean to fat mass, may better identify obese older adults at risk of osteoporosis and fractures. Nevertheless, measurement techniques and thresholds need to be validated in order to make this feasible in clinical settings.

There are several limitations to this research. The cross-sectional design limits comments on causation and the cohort was of relatively small sample size. Multivariable regression models may have exceeded the appropriate number of covariates for this sample size and as such, our results require confirmation in adequately powered studies. Our cohort consisted of generally healthy community-dwelling older adults and may not be generalisable to the wider older adult population. However, the prevalence of obesity in this cohort (47%) was consistent with that of 49% reported in the 2012 Australian Diabetes, Obesity and Lifestyle Study (32). The sample size was not sufficient to allow analyses across sarcopenic obesity categories, primarily due to the low number of participants who met the FNIH criteria for sarcopenia (2%). Nevertheless, this is consistent with estimates from a pooled analysis of international studies reporting sarcopenia prevalence of 2% in women and 1% in men according to the FNIH definition (33). Fasting glucose levels were included in multivariable models, but other measures such as glycated haemoglobin (HbA1c) or the homeostasis model assessment of insulin resistance (HOMA-IR), may be better indicators of type 2 diabetes status. Finally, as the primary focus of this study was examining lower-leg muscle density in older adults, pQCT scans were performed at the proximal tibia only which does not allow for assessment of effects on trabecular bone.

5.0 Conclusions

In conclusion, amongst components of sarcopenic obesity, higher ALM is the most consistent independent predictor of better bone health in older adults. Higher fat mass and lower muscle density appear to have no benefits for, and may even compromise, bone health and balance. Interventions which focus on improving muscle mass and composition and reducing fat mass, such as weight-bearing and resistance exercise combined with caloric restriction while maintaining adequate protein intake, may be beneficial for the prevention of excess bone loss in obese older adults.

Role of the funding body

The funding bodies had no role in the study design, conduct analysis or interpretation of data, or the decision to publish.

Author Contributions

DS, RC, KS and PE conceived and designed the study. DS, CSL, LM, JM, and AH were involved in participant recruitment, data collection and data entry. GD provided access to research tools and input on analysis and interpretation. DS accepts responsibility for integrity of the data. All authors have read and approved the manuscript.

Conflicts of Interest

None.

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References

1. Roubenoff R. Sarcopenic obesity: The confluence of two epidemics. Obes Res. 2004;12(6):887-8.

2. Studenski SA, Peters KW, Alley DE, Cawthon PM, McLean RR, Harris TB, et al. The FNIH Sarcopenia Project: Rationale, Study Description, Conference Recommendations, and Final Estimates. J Gerontol A Biol Sci Med Sci. 2014;69(5):547-58.

3. Scott D, Seibel M, Cumming R, Naganathan V, Blyth F, Le Couteur DG, et al. Sarcopenic Obesity and its Temporal Associations with Changes in Bone Mineral Density, Incident Falls and Fractures in Older Men: The Concord Health and Ageing in Men Project. J Bone Miner Res. 2017;32(3):575-83.

4. Scott D, Chandrasekara SD, Laslett LL, Cicuttini F, Ebeling PR, Jones G. Associations of Sarcopenic Obesity and Dynapenic Obesity with Bone Mineral Density and Incident Fractures Over 5–10 Years in Community-Dwelling Older Adults. Calcif Tissue Int. 2016;99(1):30-42.

5. Huo YR, Suriyaarachchi P, Gomez F, Curcio CL, Boersma D, Gunawardene P, et al. Phenotype of sarcopenic obesity in older individuals with a history of falling. Arch Gerontol Geriatr. 2016.

6. Chung JH, Hwang HJ, Shin HY, Han CH. Association between Sarcopenic Obesity and Bone Mineral Density in Middle-Aged and Elderly Korean. Ann Nutr Metab. 2016;68(2):77-84.

7. Wong AKO. A Comparison of Peripheral Imaging Technologies for Bone and Muscle Quantification: a Mixed Methods Clinical Review. Curr Osteoporos Rep. [journal article]. 2016;14(6):359-73.

8. Miljkovic I, Kuipers AL, Cauley JA, Prasad T, Lee CG, Ensrud KE, et al. Greater skeletal muscle fat infiltration is associated with higher all-cause and cardiovascular mortality in older men. J Gerontol A Biol Sci Med Sci. 2015;70(9):1133-40.

9. Frank A, Farthing J, Chilibeck P, Arnold C, Olszynski W, Kontulainen S. Community-dwelling female fallers have lower muscle density in their lower legs than non-fallers: evidence from the Saskatoon Canadian Multicentre Osteoporosis Study (CaMos) cohort. J Nutr Health Aging. 2015;19(1):113-20.

10. Frank-Wilson AW, Farthing JP, Chilibeck PD, Arnold CM, Davison KS, Olszynski WP, et al. Lower leg muscle density is independently associated with fall status in community-dwelling older adults. Osteoporos Int. [journal article]. 2016 July 01;27(7):2231-40.

11. Lang T, Cauley JA, Tylavsky F, Bauer D, Cummings S, Harris TB. Computed tomographic measurements of thigh muscle cross-sectional area and attenuation coefficient predict hip fracture: the health, aging, and body composition study. J Bone Miner Res. 2010;25(3):513-9.

12. Zamboni M, Mazzali G, Fantin F, Rossi A, Di Francesco V. Sarcopenic obesity: A new category of obesity in the elderly. Nutr Metab Cardiovasc Dis. 2008;18(5):388-95.

13. Brown WJ, Burton NW, Marshall AL, Miller YD. Reliability and validity of a modified self-administered version of the Active Australia physical activity survey in a sample of mid-age women. Aust N Z J Public Health. 2008;32(6):535-41.

14. Scott D, Daly RM, Sanders KM, Ebeling PR. Fall and Fracture Risk in Sarcopenia and Dynapenia With and Without Obesity: the Role of Lifestyle Interventions. Curr Osteoporos Rep. 2015;13(4):235-44.

15. Scott D, Trbojevic T, Skinner E, Clark R, Levinger P, Haines T, et al. Associations of calf inter-and intra-muscular adipose tissue with cardiometabolic health and physical function in community-dwelling older adults. J Musculoskelet Neuronal Interact. 2015;15(4):350-7.

16. Edwards MH, Gregson CL, Patel HP, Jameson KA, Harvey NC, Sayer AA, et al. Muscle size, strength and physical performance and their associations with bone structure in the Hertfordshire Cohort Study. J Bone Miner Res. 2013;28(11):2295-304.

17. Pollock NK, Laing EM, Baile CA, Hamrick MW, Hall DB, Lewis RD. Is adiposity advantageous for bone strength? A peripheral quantitative computed tomography study in late adolescent females. The American Journal of Clinical Nutrition. 2007 November 1, 2007;86(5):1530-8.

18. Clark RA, Bryant AL, Pua Y, McCrory P, Bennell K, Hunt M. Validity and reliability of the Nintendo Wii Balance Board for assessment of standing balance. Gait Posture. 2010;31(3):307-10.

19. Huurnink A, Fransz DP, Kingma I, van Dieën JH. Comparison of a laboratory grade force platform with a Nintendo Wii Balance Board on measurement of postural control in single-leg stance balance tasks. J Biomech. 2013;46(7):1392-5.

20. Waters D, Hale L, Grant A, Herbison P, Goulding A. Osteoporosis and gait and balance disturbances in older sarcopenic obese New Zealanders. Osteoporos Int. 2010;21(2):351-7.

21. Edwards MH, Ward KA, Ntani G, Parsons C, Thompson J, Sayer AA, et al. Lean mass and fat mass have differing associations with bone microarchitecture assessed by high resolution peripheral quantitative computed tomography in men and women from the Hertfordshire Cohort Study. Bone. 2015 12//;81:145-51.

22. Frank A, Lorbergs A, Chilibeck P, Farthing J, Kontulainen S. Muscle cross sectional area and grip torque contraction types are similarly related to pQCT derived bone strength

indices in the radii of older healthy adults. J Musculoskelet Neuronal Interact. 2010;10(2):136-41.

23. Hahn MH, Won Y-Y. Bone Mineral Density and Fatty Degeneration of Thigh Muscles Measured by Computed Tomography in Hip Fracture Patients. Journal of Bone Metabolism. 2016;23(4):215-21.

24. Lorbergs A, Noseworthy M, Adachi J, Stratford P, MacIntyre N. Fat Infiltration in the Leg is Associated with Bone Geometry and Physical Function in Healthy Older Women. Calcif Tissue Int. 2015 2015/10/01;97(4):353-63.

25. Beasley LE, Koster A, Newman AB, Javaid MK, Ferrucci L, Kritchevsky SB, et al. Inflammation and race and gender differences in computerized tomography-measured adipose depots. Obesity. 2009;17(5):1062-9.

26. Hue O, Simoneau M, Marcotte J, Berrigan F, Doré J, Marceau P, et al. Body weight is a strong predictor of postural stability. Gait & Posture. 2007 6//;26(1):32-8.

27. Anderson DE, Quinn E, Parker E, Allaire BT, Muir JW, Rubin CT, et al. Associations of Computed Tomography-Based Trunk Muscle Size and Density With Balance and Falls in Older Adults. The Journals of Gerontology Series A: Biological Sciences and Medical Sciences. 2016 June 1, 2016;71(6):811-6.

28. Inacio M, Ryan AS, Bair WN, Prettyman M, Beamer BA, Rogers MW. Gluteal muscle composition differentiates fallers from non-fallers in community dwelling older adults. BMC Geriatr. 2014;14(1):1471-2318.

29. Leslie WD, Orwoll ES, Nielson CM, Morin SN, Majumdar SR, Johansson H, et al. Estimated Lean Mass and Fat Mass Differentially Affect Femoral Bone Density and Strength Index But Are Not FRAX Independent Risk Factors for Fracture. J Bone Miner Res. 2014.

30. Compston JE, Watts NB, Chapurlat R, Cooper C, Boonen S, Greenspan S, et al. Obesity is not protective against fracture in postmenopausal women: GLOW. Am J Med. 2011;124(11):1043-50.

31. Lou Y, Edmonds SW, Jones MP, Ullrich F, Wehby GL, Cram P, et al. Predictors of bone mineral density testing among older women on Medicare. Osteoporos Int. [journal article]. 2016:1-10.

32. Tanamas SK, Shaw JE, Backholer K, Magliano DJ, Peeters A. Twelve-year weight change, waist circumference change and incident obesity: the Australian diabetes, obesity and lifestyle study. Obesity (Silver Spring). 2014 Jun;22(6):1538-45.

33. McLean RR, Shardell MD, Alley DE, Cawthon PM, Fragala MS, Harris TB, et al. Criteria for clinically relevant weakness and low lean mass and their longitudinal association with incident mobility impairment and mortality: the Foundation for the National Institutes of Health (FNIH) Sarcopenia Project. J Gerontol A Biol Sci Med Sci. 2014;69(5):576-83.

Tables

Table 1. Descriptive characteristics

	Men (N=75)	Women (N=93)	P-value for difference
Age (y)	68.5 ± 8.5	67.1 ± 8.4	0.310
Retired or pension	51 (68)	57 (61)	0.367
Self-rated health excellent or very good	26 (35)	43 (46)	0.148
Self-reported CVD	38 (51)	55 (60)	0.277
Self-reported diabetes	17 (23)	21 (23)	0.989
Self-reported osteoporosis	1 (1)	10 (11)	**0.014**
Fasting glucose (mmol/L), median (IQR)	5.8 (5.3, 6.4)	5.5 (5.2, 6.5)	0.280
Total cholesterol (mmol/L)	4.5 ± 1.2	4.8 ± 1.0	**0.033**
HDL cholesterol (mmol/L)	1.3 ± 0.4	1.6 ± 0.4	**<0.001**
Triglycerides (mmol/L), median (IQR)	1.1 (0.9, 1.6)	1.3 (1.0, 1.6)	0.440
25OHD (nmol/L)	57.8 ± 20.4	61.1 ± 21.9	0.311
Total activity/week (mins)	627.4 ± 728.5	370.3 ± 419.4	**0.009**
BMI (kg/m^2)	29.9 ± 5.2	31.7 ± 6.3	0.054

Total body fat (%)	29.1± 5.9	42.8 ± 6.4	**<0.001**
ALM (kg)	26.1 ± 3.7	18.5 ± 4.3	**<0.001**
Whole-body aBMD (g/cm^2)	1.04 ± 0.14	0.88 ± 0.13	**<0.001**
Proximal tibia cortical vBMD (mg/cm^3)	1051.1 ± 38.5	1036.3 ± 42.7	**0.020**
Lower-leg muscle CSA (mm^2)	8197.8 ± 1513.7	6359.4 ± 1258.6	**<0.001**
Lower-leg muscle density (mg/cm^3)	71.7 ± 4.7	72.1 ± 4.1	0.580
Hand grip strength (kg)	40.0 ± 9.0	23.4 ±	**<0.001**

All data are mean ± SD or frequency (%) unless otherwise specified. Abbreviations: CVD; cardiovascular disease, HDL; high-density lipoprotein, 25OHD; 25-hydroxyvitamin D, BMI; body mass index, ALM; appendicular lean mass, aBMD; areal bone mineral density, vBMD; areal bone mineral density, CSA; cross-sectional area.

Table 2. Pearson correlations (P-values) for components of sarcopenic obesity and proximal tibial bone parameters in men.

	ALM (kg)	Hand grip strength (kg)	BMI (kg/m^2)	Total body fat (%)	Lower-leg muscle density (mg/cm^3)	Whole-bo aBMD (g/cm^2)
ALM (kg)	-					
Hand grip strength (kg)	**0.36 (0.002)**	-				
BMI (kg/m^2)	**0.68 (<0.001)**	0.07 (0.550)	-			
Total body fat (%)	**0.30 (0.009)**	0.01 (0.947)	**0.715 (<0.001)**	**-**		
Lower-leg muscle density (mg/cm^3)	**-0.22** (0.063)	**0.242 (0.037)**	**-0.35 (0.002)**	**-0.41 (<0.001)**	**-**	
Whole-body aBMD (g/cm^2)	**0.53 (<0.001)**	0.154 (0.188)	**0.40 (<0.001)**	0.10 (0.385)	-0.13 (0.263)	**-**
Proximal tibia cortical vBMD (mg/cm^3)	0.03 (0.788)	0.06 (0.640)	-0.11 (0.329)	-0.19 (0.111)	**0.29 (0.010)**	0.21 (0.073)
Proximal tibia cortical area (mm^2)	**0.53 (<0.001)**	**0.24 (0.038)**	0.18 (0.116)	-0.04 (0.738)	-0.11 (0.348)	**0.65 (<0.001)**
Proximal tibia cortical thickness (mm)	**0.28 (0.014)**	0.150 (0.200)	0.02 (0.892)	-0.13 (0.263)	-0.01 (0.996)	**0.45 (<0.001)**

Abbreviations: ALM; appendicular lean mass, BMI; body mass index, aBMD; areal bone mineral density, vBMD; volumetric bone mineral density.

Table 3. Pearson correlations (P-values) for components of sarcopenic obesity and proximal tibial bone parameters in women.

	ALM (kg)	Hand grip strength (kg)	BMI (kg/m^2)	Total body fat (%)	Lower-leg muscle density (mg/cm^3)	Whole-bo aBMD (g/cm^2)
ALM (kg)	-					
Hand grip strength (kg)	**0.34** **(<0.001)**	-				
BMI (kg/m^2)	**0.72** **(<0.001)**	0.08 (0.438)	-			
Total body fat (%)	0.03 (0.752)	-0.16 (0.136)	**0.60** **(<0.001)**	**-**		
Lower-leg muscle density (mg/cm^3)	**-0.28** **(0.007)**	**0.24** **(0.020)**	**-0.24** **(0.021)**	-0.03 (0.796)	**-**	
Whole-body aBMD (g/cm^2)	**0.55** **(<0.001)**	0.186 (0.074)	**0.55** **(<0.001)**	0.18 (0.086)	**-0.13** **(0.227)**	**-**
Proximal tibia cortical vBMD (mg/cm^3)	**0.24** **(0.021)**	**0.24** **(0.018)**	**0.23** **(0.025)**	**0.21** **(0.048)**	0.13 (0.199)	**0.36** **(<0.001)**
Proximal tibia cortical area (mm^2)	**0.59** **(<0.001)**	**0.30** **(0.004)**	**0.45** **(<0.001)**	0.14 (0.173)	-0.01 (0.910)	**0.63** **(<0.001)**

Proximal tibia cortical thickness (mm)	**0.39 (<0.001)**	**0.29 (0.005)**	**0.35 (0.001)**	**0.21 (0.042)**	0.08 (0.474)	**0.51 (<0.001)**

Abbreviations: ALM; appendicular lean mass, BMI; body mass index, aBMD; areal bone mineral density, vBMD; volumetric bone mineral density.

Table 4. Multivariable linear regression analyses exploring associations between sarcopenic obesity components and proximal tibial bone parameters.

	Whole-body aBMD (g/cm^2)	Proximal tibia cortical vBMD (mg/cm^3)	Proximal tibia cortical area (mm^2)	Proximal tibia cortical thickness (mm)	Proximal tibia SSI (mm^3)
			Non-obese men (N=42)		
Adjusted R^2	*0.24*	*-0.13*	*0.41*	*0.04*	*0.44*
ALM (kg)	**0.02 (0.01, 0.03)**	0.04 (-4.28, 4.35)	**9.37 (5.11, 13.63)**	0.05 (-0.03, 0.12)	**122.41 (74.32, 170.51)**
Hand grip strength (kg)	-0.01 (-0.01, 0.01)	-0.39 (-2.02, 1.25)	-0.09 (-1.70, 1.52)	-0.01 (-0.04, 0.02)	12.38 (-5.81, 30.57)
Total body fat (%)	-0.01 (-0.01, 0.01)	-0.39 (-3.68, 2.90)	-1.73 (-4.97, 1.52)	-0.03 (-0.08, 0.03)	-9.49 (-46.14, 27.16)
Muscle density (mg/cm^3)	-0.01 (-0.02, 0.01)	0.17 (-4.28, 4.63)	**-4.55 (-8.95, -0.16)**	-0.06 (-0.13, 0.02)	-32.61 (-82.25, 17.04)
			Obese men (N=33)		

Adjusted R^2	*0.19*	*0.07*	*0.25*	*0.05*	*0.21*
ALM (kg)	**0.03 (0.01, 0.05)**	1.73 (-3.36, 6.82)	**6.57 (1.22, 11.92)**	0.05 (-0.04, 0.13)	**54.44 (5.48, 103.41)**
Hand grip strength (kg)	0.01 (-0.01, 0.01)	-0.91 (-2.85, 1.03)	1.33 (-0.71, 3.37)	0.01 (-0.02, 0.05)	13.58 (-5.13, 32.29)
Total body fat (%)	-0.01 (-0.02, 0.01)	1.17 (-5.66, 3.33)	-4.33 (-9.03, 0.43)	-0.05 (-0.12, 0.03)	-31.70 (-74.94, 11.54)
Muscle density (mg/cm^3)	0.01 (-0.01, 0.02)	2.57 (-0.67, 5.81)	0.75 (-2.66, 4.16)	-0.01 (-0.05, 0.05)	6.77 (-24.45, 37.98)
			Non-obese women (N=36)		
Adjusted R^2	*0.19*	*0.10*	*0.35*	*0.22*	*0.34*
ALM (kg)	**0.01 (0.01, 0.02)**	-0.86 (-5.96, 4.24)	**5.01 (0.54, 9.48)**	0.03 (-0.05, 0.06)	**68.01 (23.48, 112.55)**
Hand grip strength (kg)	0.01 (-0.01, 0.01)	1.99 (-1.48, 5.46)	0.63 (-2.41, 3.68)	0.01 (-0.05, 0.06)	4.70 (-25.65, 35.05)
Total body fat (%)	0.01 (-0.01, 0.01)	3.20 (-0.41, 6.80)	1.71 (-1.46, 4.87)	0.04 (-0.02, 0.09)	2.34 (-29.16, 33.85)
Muscle density (mg/cm^3)	0.01 (-0.01, 0.01)	-1.49 (-6.46, 3.47)	-0.36 (-4.71, 4.00)	-0.01 (-0.08, 0.07)	4.57 (-38.83, 47.96)
			Obese women (N=57)		
Adjusted R^2	*0.38*	*0.24*	*0.46*	*0.29*	*0.41*
ALM (kg)	**0.03 (0.02, 0.04)**	**3.91 (0.33, 7.50)**	**10.87 (7.59, 14.14)**	**0.12 (0.06, 0.18)**	**94.04 (64.30, 123.78)**

Hand grip strength (kg)	-0.01 (-0.01, 0.01)	-0.10 (-2.07, 1.87)	-1.02 (-2.81, 0.78)	-0.01 (-0.04, 0.03)	-9.44 (-25.75, 6.87)
Total body fat (%)	-0.01 (-0.01, 0.01)	1.68 (-1.43, 4.79)	-0.47 (-3.30, 2.37)	0.01 (-0.05, 0.06)	-22.88 (-48.64, 2.89)
Muscle density (mg/cm^3)	0.01 (-0.01, 0.01)	**2.91 (0.02, 5.80)**	**2.70 (0.06, 5.33)**	0.05 (-0.01, 0.09)	14.84 (-9.10, 38.79)

Data are regression coefficients and (95% CI). All models are adjusted for ALM, hand grip strength, body fat and muscle density, plus age and fasting glucose. Abbreviations: ALM; appendicular lean mass, aBMD; areal bone mineral density, vBMD; volumetric bone mineral density, SSI; stress-strain index