**Associations of sarcopenic obesity and dynapenic obesity with bone mineral density and incident fractures over five to 10 years in community-dwelling older adults**

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**Abstract**

**Purpose:** To determine whether low muscle mass (sarcopenia) or strength (dynapenia), in the presence of obesity, are associated with increased risk for osteoporosis and non-vertebral fracture over five to 10 years in community-dwelling older adults.

**Methods:**N**=**1089 volunteers (mean±SD age 62±7 years; 51% female)participated at baseline and 761 attended follow-up clinics (mean 5.1±0.5 years later). Total body, total hip and spine BMD, and appendicular lean and total fat mass, were assessed by DXA. Sarcopenic obesity and dynapenic obesity were defined as lowest sex-specific tertiles for appendicular lean mass or lower-limb strength, respectively, and the highest sex-specific tertile for total fat mass. Fractures were self-reported on three occasions over 10.7±0.7 years in 563 participants.

**Results**: Obese alone participants had significantly higher BMD at all sites compared with non-sarcopenic non-obese. Sarcopenic obese and dynapenic obese men had lower spine and total body BMD, respectively, and sarcopenic obese women had lower total hip BMD, compared with obese alone (all P<0.05). Sarcopenic obese men had higher non-vertebral fracture rates compared to non-sarcopenic non-obese (incidence rate ratio: 3.0; 95% CI 1.7-5.5), and obese alone (3.6; 1.7-7.4). Sarcopenic obese women had higher fracture rates compared with obese alone (2.8; 1.4-5.6), but this was non-significant after adjustment for total hip BMD.

**Conclusions:** Sarcopenic and dynapenic obese older adults may have increased risk of osteoporosis and non-vertebral fracture relative to obese alone counterparts. Sarcopenic and dynapenic obese individuals potentially represent a subset of the obese older adult population who require closer monitoring of bone health during ageing.

**Keywords:** sarcopenia, dynapenia, obesity, osteoporosis, fracture

**Mini Abstract**

Low muscle mass (sarcopenia) and strength (dynapenia) may offset the protective effect of obesity for osteoporosis and fracture. We demonstrated that sarcopenic and dynapenic obese older adults have lower BMD than obese alone, and sarcopenic obese men have increased rates of non-vertebral fracture over 10 years.

**Introduction**

Ageing is associated with changes in body composition and physical function. The decline in muscle function during ageing was originally attributed to loss of muscle mass (sarcopenia) [1] but subsequent research has demonstrated that strength loss substantially outpaces muscle loss [2] and that its association with functional decline is independent of muscle mass [3]. It has therefore been suggested that loss of strength (dynapenia) and sarcopenia should be considered separate processes [4]. While sarcopenia is likely less closely associated with falls risk compared to dynapenia [5], given that both muscle mass and strength are positively associated with bone health in older adults [6], those with either condition may have an increased risk for fracture.

Obesity increases the risk of falls, but not necessarily fall-related injuries [7]. A protective effect of obesity for fracture may be mediated by increased bone mineral density (BMD) and soft-tissue padding at certain sites [8]. Despite this individual protective effect, with obesity epidemics and ageing populations common in developing countries, a substantial proportion of fractures now occur in the overweight and obese older adult population [9]. Moreover, given that sarcopenia and dynapenia may confer low BMD risk, it is possible that obese individuals with these conditions (“sarcopenic obesity” or “dynapenic obesity”) do not demonstrate BMD equivalent to that of those with obesity alone. Indeed, a previous study has demonstrated that the prevalence of osteoporosis at the femur is two-fold greater in sarcopenic obese compared to obese alone older adults [10], although no previous study has examined associations of dynapenic obesity and BMD. This is relevant given that we recently reported that dynapenic obesity, but not sarcopenic obesity, is associated with significant increases in risk factors for falls [11], and so dynapenic obesity may confer a greater fracture risk in older adults than does sarcopenic obesity. The aim of the present study was to determine whether baseline BMD, its change over five years, or self-reported fracture rates over 10-years, are significantly different in sarcopenic and dynapenic obese older adults compared with obese and non-obese older adults without sarcopenia or dynapenia.

**Methods**

***Study Design and Participants***

This study was conducted within the Tasmanian Older Adult Cohort Study (TASOAC), a prospective population-based study that consisted of 1,100 males and females (98% Caucasian) aged 50-79 years at baseline. Participants were selected from electoral rolls in southern Tasmania (population 229,000) using stratified simple random sampling by sex without replacement (response rate 57%). The Southern Tasmanian Health and Medical Human Research Ethics Committee approved the study, and written informed consent was obtained from all participants. Participants who had a contraindication for MRI and those that were institutionalised were excluded. Participants attended a baseline clinic between March 2002 and September 2004, and were invited to attend a follow-up clinic five to six years after the baseline visit. Participants also self-reported fractures at this follow-up clinic, as well as at study assessments conducted approximately two to three and 10 to 12 years after baseline.

***Measurements***

At baseline and five-year follow-up clinic visits, height was measured to the nearest 0.1 cm using a Leicester stadiometer (Invicta, Leicester, UK). Weight was measured to the nearest 0.1 kg using electronic scales (Heine, Dover, USA). Body mass index (BMI; kg/m2) was calculated. Waist circumference was measured using a constant tension tape. Participants completed a questionnaire investigating employment and smoking status, and co-morbidities including cardiovascular disease, diabetes and other major illness. A comorbidity score was calculated as the total number of self reported comorbidities from a specified list. We have previously reported that the total number of comorbidities is increased in sarcopenic and dynapenic obesity [11]. Participants were also asked about the presence of pain at different body sites [12]. A validated Food Frequency Questionnaire [13] investigated dietary energy and alcohol intake and a 7-day pedometer assessment determined physical activity levels as described previously [14]. Lower-limb muscle strength was measured to the nearest kilogram in both legs simultaneously at baseline, using a dynamometer (TTM Muscular Meter, Tokyo, Japan). This test examines isometric strength, predominately of the quadriceps and hip extensors, and has been described in detail previously [15]. Participants also completed the validated Physiological Profile Assessment (PPA) to assess falls risk [16]. Standardised Z-scores were calculated based on performance in assessments of five physiological domains: knee extension strength, balance, proprioception, reaction time and edge contrast sensitivity. Falls risk scores less than 0 indicate a low risk of falls, between 0 and 1 indicate a mild increased risk, between 1 and 2 indicate a moderate increased risk, and greater than 2 indicate a high increased risk [16].

Participants underwent whole body, right hip and lumbar spine scans by dual-energy X-ray absorptiometry (DXA: Hologic Delphi densitometer, Hologic, Waltham, USA) from which bone mineral density (g/cm2) and soft tissue composition (total body fat [kg and %] and appendicular lean mass (ALM; kg) were calculated. The same densitometer was used throughout the study and quality control was performed using a spine phantom prior to testing. The longitudinal coefficient of variation for this spine phantom using our machine between 2002 and 2007 was 0.39% [17]. Osteoporosis and osteopenia were defined at the hip and spine separately using the T-score. For each site, osteoporosis was defined as a T-score below -2.5 and osteopenia as a T-score greater than or equal to -2.5, but less than -1 [18]. At study assessments conducted approximately two-to-three years, five-to-six years, and 10-12 years after baseline, participants were asked to respond to the following question: “List any fractures you may have had since your previous interview for this study. Please list these by the location of the fractures (e.g. left thumb, right wrist, etc.)”. Reported fractures were then classified as non-vertebral or vertebral according to location.

***Operational definitions of sarcopenic and dynapenic obesity***

Sarcopenic and dynapenic obesity were defined according to the measurements and cut-points established in our previous study [11]. Lean mass was calculated relative to body size using the residuals of the linear regression of appendicular lean mass (ALM) on height and total body fat as recommended by Newman and colleagues [19]. It should be noted that Newman et al., originally defined sarcopenia as the sex-specific lowest 20% of the distribution of ALM residuals, however we applied cut-points of the lowest tertiles for muscle mass and strength, and highest tertile for body fat, in order to be consistent with previous definitions of sarcopenic and dynapenic obesity [20, 21]. Specifically, sarcopenia was defined as the lowest sex-specific tertile for residuals of ALM (men <-1.09; women <-0.92), dynapenia as the lowest sex-specific tertile for lower-limb muscle strength (men <112kg; women <47.5kg), and obesity as the highest sex-specific tertile for total body fat (men ≥27.02kg; women ≥32.83kg). For the primary analyses, participants were classified into one of four categories for both sarcopenic and dynapenic obesity definitions (non-sarco/dynapenic, non-obese; non-sarco/dynapenic, obese; sarco/dynapenic, non-obese; sarco/dynapenic, obese). In order to be consistent with current multidimensional definitions of sarcopenia [22], we also conducted further analyses in which participants were classified as having both sarcopenic and dynapenic obesity, sarcopenia and dynapenia only, obesity alone, or none of sarcopenia, dynapenia or obesity.

***Statistical analyses***

Continuous and categorical variables were compared across categories of sarcopenic obesity (SO) and dynapenic obesity (DO) using one-way ANOVA and Chi-square tests, respectively. Bonferroni post-hoc tests were used to identify between-group differences when significant trends were observed. Sex-stratified multivariable linear regression analyses examined differences in baseline and five-year change in hip, spine and total body BMD for sarcopenic obesity and dynapenic obesity (and combined sarcopenic and dynapenic obesity) categories, with non-sarcopenic/dynapenic, non-obese as the reference groups, respectively. A separate analysis was performed with the obese alone category as the reference group in order to identify potential BMD differences between sarcopenic/dynapenic obese and obese alone. These analyses were adjusted for age, number of comorbidities, falls risk score physical activity, smoking status, self-reported diabetes, alcohol use and pain score, and five-year change in BMD analyses were further adjusted for baseline BMD and change in body weight. Sex-stratified Poisson regression was performed to obtain incident rate ratios for self-reported non-vertebral fractures over 10 years according to sarcopenic and dynapenic obesity categories. These analyses were adjusted initially for baseline age and falls risk score, and subsequently total hip BMD, to determine whether falls or bone health mediated associations of sarcopenic and dynapenic obesity with incident fracture rates.

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 23 (IBM, NY, USA).

# Results

One thousand and ninety-nine participants attended baseline data collection clinics. Of these, 1089 (mean ± SD age 62 ± 7 years; 51% female) completed DXA scans and were included in our analyses. According to our previously reported cut-points, the prevalence of sarcopenic obesity and dynapenic obesity was 12% and 13% respectively, and 57 (5%) participants had both sarcopenic and dynapenic obesity. Amongst all participants, 22% and 39% had baseline osteoporosis or osteopenia at total hip and spine, respectively. Prevalence of osteoporosis/osteopenia was significantly higher in females than males at both the hip (29 vs 14%, respectively, P = <0.001) and spine (44 vs 34%, respectively, P = 0.001).

Table 1 presents baseline descriptive variables according to sarcopenic and dynapenic obesity categories. Both sarcopenic obese and dynapenic obese, and sarcopenic alone and dynapenic alone, participants were significantly older than non-sarcopenic non-obese and non-dynapenic non-obese, as well as obese alone participants. There was a higher proportion of females in the dynapenic obese but not sarcopenic obese group compared with all other categories. Number of self-reported comorbidities was significantly higher for sarcopenic obese participants compared to sarcopenic alone and non-sarcopenic non-obese, and was also higher for dynapenic obese compared to all other groups. Sarcopenic obese individuals were significantly more likely to report pain compared with both non-sarcopenic non-obese and sarcopenic alone, while obese alone participants were significantly more likely to have pain than sarcopenic alone, but not non-sarcopenic non-obese. Participants in both the obese alone and dynapenic obese groups were significantly more likely to have pain compared to non-dynapenic, non-obese. The highest prevalence of total hip and spine osteoporosis/osteopenia was consistently observed in the sarcopenic and dynapenic alone groups, while the lowest prevalence of osteoporosis/osteopenia was consistently observed in the obese alone groups. A significantly higher proportion of sarcopenic obese individuals also had total hip osteoporosis/osteopenia compared with obese alone participants. Physical activity was significantly higher in non-sarcopenic non-obese and non-dynapenic non-obese participants compared with all other groups, and was also significantly higher in dynapenic alone compared with dynapenic obese participants. Falls risk scores did not differ across sarcopenic obesity categories, but dynapenic alone and dynapenic obese participants had significantly higher falls risk scores than obese alone and non-dynapenic non-obese.

Table 2 presents multivariable regression coefficients expressing BMD differences at baseline according to sarcopenic and dynapenic obesity categories. Amongst males, obese alone and sarcopenic alone participants had significantly higher and lower total hip and spine BMD, respectively, compared with the non-sarcopenic non-obese group. Sarcopenic obese males had significantly lower spine BMD compared with obese alone. Only sarcopenic alone participants had significantly lower total body BMD compared with non-sarcopenic non-obese and obese alone participants. Compared with non-dynapenic non-obese participants, obese alone and dynapenic alone males also had significantly higher and lower BMD, respectively, at total hip and spine. The dynapenic obese group had significantly lower total body BMD compared with the obese alone group. Amongst females, obese alone had significantly higher BMD at all sites compared with the non-sarcopenic non-obese group and sarcopenic alone group. Total hip and spine BMD were significantly higher for the sarcopenic obese group compared with non-sarcopenic non-obese, although total hip BMD was significantly lower for sarcopenic obese compared with obese alone participants, and the lower total body BMD of sarcopenic obese compared to obese alone also approached significance (P<0.06). Compared with non-dynapenic non-obese women, obese alone and dynapenic obese women had significantly higher BMD at all sites. When sarcopenic and dynapenic obesity were combined (Table 3), similar associations were observed. In men, sarcopenic and dynapenic alone participants had significantly lower BMD at all sites compared to non-sarcopenic and non-dynapenic non-obese, and obese alone. Sarcopenic and dynapenic obese men had significantly lower spine and total body BMD compared to obese alone, and the association for total hip BMD approached significance (P<0.07). For women, obesity alone was associated with significantly higher BMD at all sites and sarcopenic and dynapenic alone participants had significantly lower BMD at all sites compared to obese alone. Sarcopenic and dynapenic obese women had significantly higher total hip BMD compared to non-sarcopenic and non-dynapenic non-obese, but this was significantly lower when compared to obese alone.

A total of 761 participants provided complete BMD data at five-year follow-up (mean 5.1 ± 0.5 years after baseline) and 563 participants completed fracture recall at the 10-year follow-up (mean 10.7±0.7 years after baseline). Participants lost to five-year follow-up were significantly older, and had greater total body fat, lower ALM, lower leg strength, and lower total hip BMD than included participants (all P<0.05), but there were no differences in gender proportions (50 vs 51% female; P=0.473). Table 4 presents regression coefficents expressing differences in BMD changes (mg/cm2) to the five-year follow-up according to sarcopenic and dynapenic obesity categories. Amongst males, there were no differences in change in BMD according to sarcopenic obesity categories, although the dynapenic alone (B-coeffcient = -13.9; 95% CI -27.6, -0.1 mg/cm2) and dynapenic obese (-18.9; -37.0, -0.7 mg/cm2) groups had significantly greater declines in total hip BMD compared with obese alone. Dynapenic alone men also had significantly greater declines in total body BMD compared to non-dynapenic non-obese. Amongst females, all groups had significantly smaller declines in total hip BMD compared with the non-sarcopenic non-obese group, but only the obese alone group had significantly smaller declines in total body BMD. Dynapenic obese females had significantly smaller declines in spine BMD compared to obese alone (-21.2; 1.4, 41.0 mg/cm2) and dynapenic alone lost significantly less total body BMD compared with non-dynapenic, non-obese.

Incidence of hip osteoporosis/osteopenia at follow-up according to baseline sarcopenic obesity and dynapenic obesity categories is reported in Figures 1A and 1B, respectively. Only participants without prevalent hip osteoporosis/osteopenia at baseline were included in this analysis and a total of 9.8% developed osteoporosis/osteopenia after 5 years of follow-up. Non-sarcopenic non-obese and sarcopenic alone participants had significantly higher incidence of hip osteoporosis/osteopenia compared with obese alone, but not sarcopenic obese participants, whereas according to dynapenic obesity categories, non-dynapenic non-obese, dynapenic alone and dynapenic obese had significantly higher incidence of hip osteoporosis/osteopenia compared with obese alone. Figure 1C presents incidence of hip osteoporosis/osteopenia for combined sarcopenic and dynapenic obesity categories. Those with both sarcopenic and dynapenic obesity did not have increased incidence of hip osteoporosis/osteopenia, although those with sarcopenia and dynapenia alone had significantly higher incidence compared to those with obesity alone.

Amongst 563 participants who completed the 10-year follow-up (mean 10.7±0.7 years), 21% reported a total of 210 incident fractures and the majority of these (88%) were non-vertebral fractures. Incident non-vertebral fractures were significantly more common in females than males (24 vs 14%, respectively, P = 0.003). Table 5 reports incidence rate ratios for the likelihood of reporting a fracture and rate of reported fractures, respectively, over 10 years according to sarcopenic and dynapenic obesity categories. Sarcopenic obese men had over three-fold increased rate of non-vertebral fractures compared to both non-sarcopenic non-obese and obese alone counterparts, after adjustment for age, falls risk score and total hip BMD. Before adjustment for total hip BMD, obese alone women had approximately half the rate of non-vertebral fracture compared to non-sarcopenic non-obese, and the rate of fracture was almost three-fold higher for sarcopenic obese compared to obese alone women. These associations were not significant after adjustment for baseline total hip BMD, although the higher rate for sarcopenic obese women compared to obese women approached significance (P=0.07). Dynapenic obese men and women did not have increased rates of non-vertebral fracture, but obese alone men and women had significantly reduced rates of fracture compared to non-dynapenic non-obese. This association remained significant in men, but not in women, after adjustment for total hip BMD,.

When combined sarcopenic and dynapenic obesity were examined (Table 5), the number of participants in each group was substantially reduced and no significant associations with incident non-vertebral fractures were observed in men. However, in women, there was a significantly lower fracture rate in both obese alone and sarcopenic and dynapenic alone compared to non-sarcopenic and non-dynapenic non-obese. Sarcopenic and dynapenic obese women had over three-fold higher rate of fracture than obese alone, but this association was no longer significant (P=0.07) after adjustment for total hip BMD.

**Discussion**

The primary finding of this population-based study of community-dwelling older adults was that sarcopenic obese older men have over three-fold increased rate of self-reported fractures over 10 years compared to both non-sarcopenic non-obese and obese alone counterparts. Older women with sarcopenic obesity, and also combined sarcopenic and dynapenic obesity, similarly had increased risk of fracture compared to obese alone counterparts, but this was mediated by BMD. Inconsistent associations were observed for change in BMD over five years according to sarcopenic and dynapenic obesity categories, however obese alone, but not sarcopenic obese, participants demonstrated a lower incidence of osteoporosis and osteopenia over five years, and dynapenic obese participants had significantly increased incidence of osteoporosis and osteopenia compared to obese alone. Taken together, these results suggest that sarcopenic and dynapenic obesity may be associated with poorer bone health and increased fracture risk, at least in comparison with obesity alone, but that mechanisms by which these conditions contribute to increased fracture risk may be sex-specific.

This is the first prospective population-based study to investigate associations of sarcopenic and dynapenic obesity with BMD and fractures in older adults. Baseline results from a previous falls prevention trial in New Zealand reported that the highest prevalence of femoral neck osteoporosis (22%) was observed in sarcopenic alone, followed by sarcopenic obese (17%), non-sarcopenic non-obese (12%) and obese alone (7%) older adults, although no significant differences were reported between these groups [10]. We similarly observed significantly higher prevalence of total hip osteoporosis/osteopenia in sarcopenic alone (36%) compared to obese alone (7%) individuals at baseline, and prevalence was also significantly higher for sarcopenic obese (18%) compared with obese alone. The prevalence of total hip osteoporosis/osteopenia was, however, significantly lower for sarcopenic obese compared with sarcopenic alone, consistent with a previous small study of Canadian obese post-menopausal women that suggested that obesity may provide some protection against osteoporosis in sarcopenic individuals [23].

The effects of fat mass on bone health are controversial. A recent cross-sectional study of over 17,000 participants demonstrated that both low muscle mass and strength were generally positively associated with DXA-assessed BMD, but fat mass demonstrated sex-specific negative associations with BMD [24]. Previous cross-sectional analyses of the Hertfordshire Cohort Study similarly reported that both muscle mass and strength are positively associated with bone size and strength [6], but conversely found fat mass demonstrates positive associations with trabecular density and number assessed by high-resolution pQCT even after adjustment for lean mass [25]. On the other hand, a case-control study of obese post-menopausal women demonstrated that lean mass has a stronger positive effect than fat on bone biomechanical parameters [26]. The effects of body composition on BMD may be sex-specific as our cross-sectional analyses demonstrated that sarcopenic obese and dynapenic obese women generally had significantly higher BMD than non-sarcopenic or non-dynapenic obese counterparts, whereas sarcopenic obese and dynapenic obese men had similar BMD to non-sarcopenic or non-dynapenic obese counterparts. This suggests that lower muscle mass and strength, at least in the presence of obesity, has less adverse effects for bone health of older women than men. This may be related to the key role of fat mass in oestrogen levels in women, given that oestrogens regulate bone mass and strength through actions on osteoblasts and osteoclasts [27].

We also found that the five-year incidence of total hip osteoporosis is significantly higher in sarcopenic alone, dynapenic alone and dynapenic obese older adults compared with obese alone. Nevertheless, after adjustment for multiple confounders inconsistent associations with loss of BMD over five years were observed; only dynapenia alone and dynapenic obesity in men was associated with greater declines in BMD (relative to obese alone) in this study. It is unclear why sarcopenia and dynapenia, with or without obesity, are associated with lower BMD in cross-sectional analyses, but generally do not contribute to greater declines in BMD during ageing. It is possible that because most participants maintained similar body composition status over five years (74% remained in the same sarcopenic obesity category at follow-up as at baseline) their BMD trajectories also generally remained similar. It is likely that only older adults who experience substantial changes in muscle mass or fat mass would demonstrate bone mass changes over this time. Nevertheless, our finding that dynapenic and dynapenic obese males had significantly greater loss of total hip BMD over five years compared with obese alone is potentially clinically significant given previous studies have reported that dynapenic obesity is associated with poorer mobility [20, 28], a potential precursor to falls. Indeed, we have reported using data from this study that dynapenic obesity, but not sarcopenic obesity, is associated with significantly increased falls risk (determined by the PPA) over five years (13). Thus, dynapenic obese older men may experience concurrent increases in falls and decreased BMD during ageing, which in conjunction may substantially increase their risk for fracture.

Despite this, significantly increased rates of self-reported non-vertebral fracture over 10 years were observed only for sarcopenic obese, and not dynapenic obese, older adults. Non-vertebral fracture rates for sarcopenic obese men were over three-fold higher compared to both obese alone and non-sarcopenic non-obese, while sarcopenic obese women (and those with combined sarcopenic and dynapenic obesity) had two- to three-fold increased rates compared to obese alone. Somewhat surprisingly, there was no increased risk of incident non-vertebral fracture for participants with sarcopenia alone. However, a similar finding has recently been reported in an analysis of over 6,000 participants aged 65 years and older from The Osteoporotic Fractures in Men Study and the Study of Osteoporotic Fractures in Women; men and women with low BMD combined with sarcopenia, but not with sarcopenia alone, had two- to three-fold increased risk of non-vertebral fractures over eight to nine years [29]. It is possible therefore that sarcopenia is associated with increased fracture risk only in the presence of low BMD, or as demonstrated in the present study, obesity.

However, it should be noted that the increased fracture risk for women with sarcopenic obesity, and the decreased fracture risk of women with obesity alone, became non-significant after adjustment for total hip BMD. This finding suggests that reduced fracture risk in obesity alone, and increased fracture risk in sarcopenic obesity, are attributable to differences in BMD in women, but not men. Adjustment for falls risk score, also did not explain the increased fracture risk of sarcopenic obese men, and this is not surprising given we have demonstrated increased falls risk scores only in dynapenic obesity (13). Thus, the mechanism by which sarcopenic obesity increases fracture risk in men is unclear; it may be that there is residual confounding attributable to the measurement of a falls risk score, rather than incident falls, in this study. We have previously reported that low lean mass is more consistently associated with declines in physical performance in men than women [30], and so it is possible that incident falls were increased in obese men, but not women, with sarcopenia. It is also possible that increased fracture risk in sarcopenic obese men is more closely related to deleterious changes in bone microarchitecture and geometry not measured in this study, as opposed to BMD.

This study has several limitations. There was substantial loss to follow-up over 10 years and at baseline these participants were significantly older, had poorer body composition and lower total hip BMD that participants who completed the study. It is possible that associations of sarcopenic and dynapenic obesity with BMD and fracture risk differ in this population, and likely that our findings can be generalised only to healthy community-dwelling older adults. Areal BMD assessed by DXA has limitations as a predictor of fracture and future studies are required to assess effects of sarcopenic and dynapenic obesity on volumetric BMD and bone microarchitecture [31]. The duration of fracture recall was substantial and fractures were not radiographically confirmed nor were causes of fracture ascertained (eg. minimal trauma fractures). There was also a relatively small number of incident non-vertebral fractures which restricted our ability to adjust for multiple potential confounders, and there were too few vertebral fractures to allow for a meaningful analysis of this outcome. Future prospective population-based studies should incorporate regular fracture reporting, radiographic confirmation and ascertainment of causes in order to clarify the associations of sarcopenic obesity and dynapenic obesity with incident fractures at different sites in older adults. Given that we aimed to determine differences in risk for osteoporosis and fracture for sarcopenic obese and dynapenic obese compared with both non-sarcopenic non-obese and non-dynapenic non-obese, and obese alone counterparts, we performed multiple comparisons and did not adjust for these. Lastly there is no consensus definition of sarcopenic and dynapenic obesity and so we used thresholds that we have previously applied in this study [11]. The thresholds we used were based on the lowest tertile for muscle mass and strength, and highest tertile for fat mass. These cut-points differ from other commonly suggested cut-points for sarcopenia, including muscle mass within the lowest sex-specific 20% of a cohort [19] or two standard deviations below the mean of a representative young adult population [32], but are consistent with other studies of sarcopenic and dynapenic obesity [20, 21]. Furthermore, there is a clear lack of consensus as to whether sarcopenia and dynapenia should be considered separate conditions, and current definitions generally incorporate muscle function as a component of sarcopenia [22, 33, 34], rather than a separate entity, despite evidence that age-related declines in skeletal muscle mass and strength are only weakly associated [4]. It is imperitive that consensus is achieved on the nature and definition of sarcopenia and dynapenia, as future studies which continue to use different definitions of these conditions are likely to observe varying associations with BMD and fracture risk.

It should also be noted that approximately half of participants with sarcopenic obesity or dynapenic obesity in this study in fact had both conditions and it is therefore difficult to determine whether one condition alone, or the presence of both conditions, confers the greatest risk for osteoporosis and fracture. Nevertheless, our findings indicate that sarcopenic and/or dynapenic obese older adults are a segment of the obese older adult population who may not benefit from the perceived protective effect of obesity for fracture [9]. It is possible that identification of sarcopenic and dynapenic obese individuals, and prescription of BMD-enhancing and falls prevention therapies, may reduce the risk of osteoporosis and fracture in the obese older adult population. Targeted multi-modal exercise in particular may be beneficial for sarcopenic and dynapenic obese individuals given it has the potential to reduce body fat, and improve muscle mass, strength and bone health [5].

In conclusion, sarcopenic and dynapenic obese older adults may have an increased risk of osteoporosis and incident non-vertebral fracture relative to obese alone older adults. Sarcopenic and dynapenic obese individuals potentially represent a subset of the obese older adult population who require closer monitoring of bone health during ageing.

**Conflict of Interest:** David Scott, Sahan D Chandrasekara, Laura L Laslett, Flavia Cicuttini, Peter R Ebeling and Graeme Jones declare that they have no conflict of interest.

**Ethical approval:** All procedures performed in this study involving human participants were in accordance with the ethical standards of the institutional research committee and with the 1964 Helsinki declaration and its later amedments or comparable ethical standards. Written informed consent was obtained from all participants.

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**Figure 1. Five-year incidence of total hip osteoporosis/osteopenia, according to baseline sarcopenic obesity (A) and dynapenic obesity (B) categories, and combined sarcopenic andy dynapenic obesity (C).**

**Legend (A)**

NSNO = Non-sarcopenic non-obese

O = Obese alone

S = Sarcopenic alone

SO = Sarcopenic obese

a denotes significantly different to NSNO

b denotes significantly different to O

c denotes significantly different to S

d denotes significantly different to SO

**Legend (B)**

NDNO = Non-dynapenic non-obese

O = Obese alone

D = Dynapenic alone

DO = Dynapenic obese

a denotes significantly different to NDNO

b denotes significantly different to O

c denotes significantly different to D

d denotes significantly different to DO

**Legend (C)**

NSNDNO = Non-sarcopenic and non-dynapenic non-obese

O = Obese alone

SD = Sarcopenic and dynapenic alone

SDO = Sarcopenic and dynapenic obese

a denotes significantly different to NSNDNO

b denotes significantly different to O

c denotes significantly different to SD

d denotes significantly different to SDO

Table 1. Baseline descriptive characteristics according to categories of sarcopenic and dynapenic obesity.

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | Non-sarcopenic, non-obese  N=457 | Non-sarcopenic obese  N=274 | Sarcopenic non-obese N=233 | Sarcopenic obese  N=128 | Non-dynapenic, non-obese  N=419 | Non-dynapenic, obese  N=241 | Dynapenic, non-obese N=244 | Dynapenic obese  N=138 |
| Age (years) | 62.4 ±7.5c,d | 62.3±6.8c,d | 64.2±8.0a,b | 64.8±7.6a,b | 61.2±6.9c,d | 61.8±6.7c,d | 65.5±8.00a,b | 65.1±7.4a,b |
| Female (%)\* | 49% | 54% | 52% | 51% | 50%d | 48%d | 49%d | 59%a,b,c |
| Current smoker (%)\* | 12.3% | 10.3% | 16.3% | 7.0% | 13.4% | 11.3% | 14.5% | 5.8% |
| Number of comorbidities | 1.27 ± 1.27b,d | 1.64 ± 1.46a | 1.43 ± 1.33d | 1.89 ± 1.38a,c | 1.15 ± 1.17b,c,d | 1.47 ± 1.25a,d | 1.48 ± 1.37a,d | 2.18 ± 1.59a,b,c |
| Pain (%)\* | 85.3%d | 90.8%c | 82.8%b,d | 96.0%a,c | 82.1%b,d | 91.7%a | 87.2% | 92.6%a |
| Hip Osteoporosis/Osteopenia (%)\* | 24.5%b,c | 7.4%a,c,d | 35.6%a,b,d | 18.1%b,c | 22.7%b,c,d | 7.6%a,c | 34.8%a,b,d | 11.6%a,c |
| Spine Osteoporosis/Osteopenia (%)\* | 42.4%b | 26.5%a,c | 50.6%b,d | 33.9%c | 40.3%b | 26.9%a,c | 50.8%b,d | 29.7%c |
| Alcohol intake (g/day) | 16.4 ± 19.9 | 14.5 ± 18.1 | 12.8 ± 17.6 | 14.2 ±21.5 | 16.2 ± 19.1 | 16.9 ± 21.2 | 14.0 ± 19.9 | 11.1 ± 15.6 |
| Physical activity (steps/day) | 9646±3281b,c,d | 7862±3355a | 8133±3082a | 7458±3071a | 9723±3099b,c,d | 8097±3233a | 8328±3474a,d | 7284±3359a,c |
| Energy intake (kJ/day) | 7730±2849 | 7807±2880 | 7509±2723 | 7532±2911 | 7808±2896 | 7801±2812 | 7435±2825 | 7561±2990 |
| BMI (kg/m2) | 25.8±2.8b,c,d | 33.0±3.8a,c,d | 24.3±2.2a,b,d | 30.5±3.7a,b,c | 25.4±2.6b,d | 32.1±3.5a,c | 25.2±2.9b,d | 32.3±4.7a,c |
| Waist circumference (cm) | 88.4±10.1b,c,d | 106.0±9.8a,c,d | 86.0±8.6a,b,d | 102.9±10.6a,b,c | 87.5±9.7b,d | 104.7±9.6a,c | 88.0±9.7b,d | 105.1±10.7a,c |
| Total body fat (kg) | 23.0±49.8b,d | 36.8±70.6a,c | 23.9±51.3b,d | 36.7±73.3a,c | 23.2±4.9b,d | 36.1±6.8a,c | 23.4±5.2b,d | 37.6±7.6a,c |
| Trunk fat (kg) | 9.9±2.8b,d | 17.4±3.4a,c | 10.3±2.8b,d | 17.4±3.5a,c | 10.0±2.7b,d | 17.1±3.1a,c | 10.0±2.9b,d | 17.8±3.8a,c |
| ALM (kg) | 24.6±5.4b,c | 27.1±4.9a,c,d | 21.3±4.3a,b,d | 23.5±4.5b,c | 24.0±5.4b,c | 26.9±5.2a,c,d | 22.9±4.9a,b,d | 24.7±4.3b,c |
| LLS (kg) | 97.7±50.4c,d | 97.2±52.8c,d | 82.9±41.9a,b | 80.96±42.8a,b | 112.6±46.4c,d | 114.7±45.8c,d | 59.1±28.9a,b | 53.4±30.8a,b |
| Falls risk Z-score | 0.17 ± 0.87 | 0.09 ± 0.77 | 0.26 ± 0.87 | 0.28 ± 0.90 | 0.04 ± 0.73c,d | -0.01 ± 0.71c,d | 0.42 ± 0.96a,b | 0.42 ± 0.85a,b |

± Standard deviation; all tests are one-way ANOVA except \*(Chi-square tests)

aSignificant difference to non-sarcopenic/dynapenic, non obese

bSignificant difference to non-sarcopenic/dynapenic, obese

cSignificant difference to sarcopenic/dynapenic, non-obese

dSignificant difference to sarcopenic/dynapenic obese (Bonferroni post-hoc tests)

Table 2. Regression coefficients expressing baseline differences in bone mineral density (g/cm2) according to sarcopenic and dynapenic obesity categories

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| ***Males*** | | | | | | | | |
|  | Non-sarcopenic, non-obese  N=218 | Non-sarcopenic, obese  N=118 | Sarcopenic, non-obese N=105 | Sarcopenic obese  N=58 | Non-dynapenic, non-obese N=203 | Non-dynapenic, obese  N=115 | Dynapenic, non-obese N=112 | Dynapenic obese  N=51 |
| Total Hip BMD | REF | 0.04 (0.01, 0.07)\* | -0.07 (-0.10, -0.04)\*^ | 0.01 (-0.03, 0.05) | REF | 0.06 (0.03, 0.09)\* | -0.02 (-0.06, 0.01)^ | 0.03 (-0.01, 0.08) |
| Spine BMD | REF | 0.05 (0.01, 0.09)\* | -0.06 (-0.10, -0.02)\*^ | -0.02 (-0.07, 0.03)^ | REF | 0.05 (0.01, 0.09)\* | -0.06 (-0.10, -0.02)\*^ | 0.02 (-0.04, 0.07) |
| Total Body BMD | REF | 0.02 (-0.01, 0.04) | -0.05 (-0.08, -0.02)\*^ | -0.01 (-0.05, 0.02) | REF | 0.03 (0.01, 0.06)\* | -0.02 (-0.05, 0.01)^ | -0.01 (-0.05, 0.02)^ |
| ***Females*** | | | | | | | | |
|  | Non-sarcopenic, non-obese N=215 | Non-sarcopenic, obese  N=143 | Sarcopenic, non-obese N=114 | Sarcopenic obese  N=57 | Non-dynapenic, non-obese N=202 | Non-dynapenic, obese  N=113 | Dynapenic, non-obese N=112 | Dynapenic obese  N=79 |
| Total Hip BMD | REF | 0.14 (0.11, 0.17)\* | -0.01 (-0.04, 0.01)^ | 0.05 (0.02, 0.09)\*^ | REF | 0.12 (0.09, 0.15)\* | -0.01 (-0.04, 0.02)^ | 0.11 (0.07, 0.15)\* |
| Spine BMD | REF | 0.09 (0.05, 0.12)\* | -0.01 (-0.04, 0.03)^ | 0.06 (0.01, 0.10)\* | REF | 0.08 (0.05, 0.12)\* | -0.01 (-0.05, 0.03)^ | 0.07 (0.03, 0.11)\* |
| Total Body BMD | REF | 0.06 (0.03, 0.08)\* | -0.02 (-0.04, 0.01)^ | 0.03 (-0.01, 0.06) | REF | 0.06 (0.03, 0.09)\* | -0.01 (-0.03, 0.03)^ | 0.05 (0.02, 0.08)\* |

\*Significantly different to non-sarcopenic/dynapenic non-obese

^Significantly different to non-sarcopenic/dynapenic obese

Adjusted for baseline age, alcohol intake, smoking status, physical activity (steps/day), falls risk score and self-reported prevalent pain and number of co-morbidities.

Table 3. Regression coefficients expressing baseline differences in bone mineral density (g/cm2) according to combined sarcopenic and dynapenic obesity categories

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| ***Males*** | | | | |
|  | Non-sarcopenic and non-dynapenic, non-obese  N=145 | Non-sarcopenic and non-dynapenic, obese  N=88 | Sarcopenic and dynapenic, non-obese N=46 | Sarcopenic and dynapenic obese  N=24 |
| Total Hip BMD | REF | 0.05 (0.01, 0.08)\* | -0.09 (-0.13, -0.05)\*^ | -0.01 (-0.07, 0.05) |
| Spine BMD | REF | 0.04 (-0.01, 0.09) | -0.11 (-0.16, -0.05)\*^ | -0.06 (-0.06, 0.04)^ |
| Total Body BMD | REF | 0.02 (-0.01, 0.06) | -0.06 (-0.10, -0.01)\*^ | -0.04 (-0.10, 0.01)^ |
| ***Females*** | | | | |
|  | Non-sarcopenic and non-dynapenic, non-obese  N=137 | Non-sarcopenic and non-dynapenic, obese  N=83 | Sarcopenic and dynapenic, non-obese N=42 | Sarcopenic and dynapenic obese  N=22 |
| Total Hip BMD | REF | 0.14 (0.10, 0.17)\* | -0.04 (-0.08, 0.01)^ | 0.07 (0.01, 0.12)\*^ |
| Spine BMD | REF | 0.08 (0.04, 0.12)\* | -0.04 (-0.10, 0.01)\*^ | 0.04 (-0.02, 0.11) |
| Total Body BMD | REF | 0.05 (0.02, 0.08)\* | -0.03 (-0.07, 0.01)^ | 0.01 (-0.04, 0.06) |

\*Significantly different to non-sarcopenic and dynapenic non-obese

^Significantly different to non-sarcopenic and dynapenic obese

Adjusted for baseline age, alcohol intake, smoking status, physical activity (steps/day), falls risk score and self-reported prevalent pain and number of co-morbidities.

Table 4. Regression coefficients expressing differences in change in BMD (mg/cm2) from baseline visit to 5-year follow-up according to sarcopenic and dynapenic obesity categories.

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| ***Males*** | | | | | | | | | |
|  | Non-sarcopenic, non-obese N=170 | Non-sarcopenic, obese  N=86 | Sarcopenic, non-obese  N=70 | Sarcopenic obese  N=37 | Non-dynapenic, non-obese N=153 | Non-dynapenic, obese  N=87 | | Dynapenic, non-obese N=83 | Dynapenic obese  N=31 |
| Total Hip BMD | REF | 5.64 (-5.71, 16.98) | -2.36 (-14.74, 10.01) | 1.78 (-14.24, 17.79) | REF | 8.97 (-2.65, 20.60) | | -4.88 (-16.98, 7.22)^ | -9.89 (-27.33, 7.54)^ |
| Spine BMD | REF | 0.05 (-13.64, 13.75) | -12.69 (-27.49, 2.11) | 0.80 (-18.65, 20.25) | REF | 0.62(-12.68, 13.93) | | 7.49 (-6.72, 21.69) | 5.83 (-14.41, 26.08) |
| Total Body BMD | REF | 5.45 (-42.97, 32.07) | 14.09 (-26.76, 54.94) | -7.39 (-60.79, 46.01) | REF | -4.08 (-28.67, 20.51) | | -27.46 (-53.37, -1.55)\* | -9.38 (-46.89, 28.13) |
| ***Females*** | | | | | | | | | |
|  | Non-sarcopenic, non-obese N=157 | Non-sarcopenic, obese  N=98 | Sarcopenic, non-obese N=77 | Sarcopenic obese  N=34 | Non-dynapenic, non-obese N=158 | | Non-dynapenic, obese  N=73 | Dynapenic, non-obese N=71 | Dynapenic obese  N=54 |
| Total Hip BMD | REF | 14.54 (1.14, 27.93)\* | 16.07 (3.35, 28.78)\* | 20.49 (3.06, 37.93)\* | REF | | 12.48 (-1.93, 26.90) | 1.08 (-12.46, 14.61) | 11.34 (-4.47, 27.14) |
| Spine BMD | REF | -0.65 (-15.89, 14.59) | 8.63 (-6.70, 23.96) | 12.76 (-8.33, 33.85) | REF | | -3.88 (-20.18, 12.42) | 13.24 (-2.66, 29.13) | 16.44 (-1.74, 34.62)^ |
| Total Body BMD | REF | 20.93 (-3.24, 45.09) | 21.48 (-2.91, 45.88) | 1.53 (-31.77, 34.84) | REF | | 21.845 (-4.54, 47.43) | 26.71 (1.23, 52.18)\* | 19.27 (-9.85, 48.39) |

\*Significantly different to non-sarcopenic/dynapenic, non-obese

^Significantly different to non-sarcopenic/dynapenic, obese

Adjusted for baseline age, alcohol intake, smoking status, physical activity (steps/day), BMD (at the relevant site), falls risk score, self-reported pain and number of co-morbidities, and change in weight from baseline to follow-up.

Table 5. Incidence rate ratios (95% CI) for self-reported non-vertebral fractures over 10 years according to sarcopenic and dynapenic obesity, and combined sarcopenic and dynapenic obesity, categories.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| ***Males*** | | | | | |
|  | Non-sarcopenic, non-obese  N=134 | Non-sarcopenic, obese  N=70 | Sarcopenic, non-obese  N=50 | Sarcopenic obese  N=27 | *SO vs O^* |
| Model 1 | REF | 0.82 (0.43, 1.57) | 0.88 (0.43, 1.81) | **3.03 (1.66, 5.51)** | **3.70 (1.78, 7.67)** |
| Model 2 | REF | 0.85 (0.44, 1.63) | 0.83 (0.40, 1.72) | **3.03 (1.66, 5.51)** | **3.56 (1.71, 7.40)** |
|  | Non-dynapenic, non-obese  N=122 | Non-dynapenic, obese  N=69 | Dynapenic, non-obese  N=61 | Dynapenic obese  N=24 | *DO vs O^* |
| Model 1 | REF | 1.32 (0.79, 2.19) | **0.30 (0.13, 0.74)** | 0.67 (0.26, 1.73) | 0.51 (0.19, 1.34) |
| Model 2 | REF | 1.43 (0.85, 2.39) | **0.27 (0.11, 0.66)** | 0.66 (0.25, 1.71) | 0.70 (0.42, 1.17) |
|  | Non-sarcopenic and non-dynapenic, non-obese  N=94 | Non-sarcopenic and non-dynapenic, obese  N=57 | Sarcopenic and dynapenic, non-obese  N=22 | Sarcopenic and dynapenic obese  N=14 | *SDO vs O^* |
| Model 1 | REF | 0.74 (0.38, 1.42) | 0.44 (0.15, 1.30) | 0.89 (0.33, 2.36) | 1.21 (0.42, 3.47) |
| Model 2 | REF | 0.71 (0.36, 1.37) | 0.50 (0.16, 1.51) | 0.90 (0.34, 2.39) | 1.28 (0.44, 3.69) |
| ***Females*** | | | | | |
|  | Non-sarcopenic, non-obese  N=124 | Non-sarcopenic, obese  N=76 | Sarcopenic, non-obese  N=58 | Sarcopenic obese  N=24 | *SO vs O^* |
| Model 1 | REF | **0.48 (0.28, 0.82)** | 0.75 (0.46, 1.23) | 1.35 (0.77, 2.36) | **2.82 (1.42, 5.60)** |
| Model 2 | REF | 0.69 (0.39, 1.23) | 0.74 (0.45, 1.21) | 1.34 (0.78, 2.33) | 1.93 (0.94, 3.98) |
|  | Non-dynapenic, non-obese  N=123 | Non-dynapenic, obese  N=58 | Dynapenic, non-obese  N=54 | Dynapenic obese  N=38 | *DO vs O^* |
| Model 1 | REF | **0.53 (0.30, 0.94)** | 0.65 (0.38, 1.10) | 0.84 (0.48, 1.25) | 1.58 (0.78, 3.19) |
| Model 2 | REF | 0.80 (0.44, 1.44) | 0.64 (0.38, 1.10) | 1.12 (0.63, 1.99) | 1.26 (0.69, 2.28) |
|  | Non-sarcopenic and non-dynapenic, non-obese  N=90 | Non-sarcopenic and non-dynapenic, obese  N=46 | Sarcopenic and dynapenic, non-obese  N=21 | Sarcopenic and dynapenic obese  N=10 | *SDO vs O^* |
| Model 1 | REF | **0.39 (0.19, 0.79)** | **0.39 (0.16, 0.96)** | 1.26 (0.58, 2.73) | **3.27 (1.25, 8.59)** |
| Model 2 | REF | 0.55 (0.25, 1.19) | **0.39 (0.16, 0.95)** | 1.37 (0.63, 3.00) | 2.51 (0.93, 6.74) |

^Odds/incidence rate ratios for sarcopenic obesity (SO), dynapenic obesity (DO) or combined sarcopenic and dynapenic obesity (SDO) with obesity alone set as the reference category.

Model 1 adjusted for baseline age and falls risk score.

Model 2 adjusted for Model 1 plus total hip BMD at baseline.

OR = odds ratio; CI = confidence interval; IRR = incidence rate ratio. Bold text indicates significant at P<0.05.

**Figure 1 A**

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**Figure 1B**

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**Figure 1C**

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