

Musculoskeletal Deterioration in Men Accompanies Increases in Body Fat

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Objective: To examine body fat and musculoskeletal changes in men over 5 years.

Design and Methods: Body composition was evaluated for men in the Geelong Osteoporosis Study using whole body dual energy X-ray absorptiometry (DXA) during two time-periods. DXA was performed for 1329 men (25-96 years) during 2001-2006 and for 900 men (25-98 years), 2006-2011. The masses of fat, lean, and bone were expressed relative to the square of height (kg/m²). Each compartment was also expressed as a percentage relative to body weight (%fat, %lean, %bone).

Results: Mean BMI increased from 26.9 kg/m² in 2001-2006, to 27.2 kg/m² in 2006-2011 ($P = 0.04$). Mean fat mass increased by 9.0% from 6.98 kg/m² (95%CI 6.84-7.11) in 2001-2006, to 7.60 kg/m² (7.44-7.77) in 2006-2011 ($P < 0.001$); mean lean mass decreased by 0.9%, from 18.92 kg/m² (18.83-19.01) to 18.75 kg/m² (18.64-18.86) ($P = 0.02$), and mean bone mass decreased 1.6% from 1.041 kg/m² (1.034-1.047), to 1.024 kg/m² (1.016-1.032). Mean %fat increased from 23.4% to 25.2%, mean %lean decreased from 72.6% to 70.9% and mean %bone decreased from 4.0% to 3.9% (all $P < 0.05$).

Conclusions: An increase in BMI, which reflects a substantial increase in body fat mass and declines in both lean and bone mass was reported. This may have implications for future development of bone fragility, sarcopenia, and sarcopenic obesity.

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Introduction

The obesity epidemic is usually monitored in terms of the body mass index (BMI) (1). While this index can be used for tracking population changes in weight-for-height and is useful as a surrogate marker for obesity, the index masks relative changes in body fat mass, lean mass, and bone (2). Accumulation of excess body fat is associated with an increased risk for type 2 diabetes and cardiovascular disease (3) and physical problems including sleep apnea (4) and knee osteoarthritis (5). A decline in muscle mass, quality and strength such as that observed with ageing, and known as sarcopenia, can contribute to frailty, decreased independence and diminished quality of life (6). When sarcopenia co-exists with obesity, the condition is referred to as sarcopenic obesity (7). Loss of bone mineral from the skeleton can result in osteoporosis and increased risk for fragility fracture, with consequent pain, loss of confidence, and independence (8,9). Changes in any of the components of body composition are likely to impact on bone structure and strength.

Therefore, temporal changes in body composition at a population level may have important consequences for the health and well-being of that population. Detrimental changes in body composition

are likely to increase healthcare utilization and cost. Yet, with the emergence of the obesity epidemic and evident accumulation of visceral body fat, most attention has focused on the burgeoning burden of cardiometabolic disease (10). Few reports have monitored patterns of change in the musculoskeletal components of body composition at the population level. Therefore, we aimed to describe changes in lean mass, fat mass, and bone in a population-based cohort of men over a period of 5 years.

Methods and Procedures

Subjects

The men included for this analysis were drawn from the Geelong Osteoporosis Study (GOS), an age-stratified population-based cohort study of adults, randomly selected from the Commonwealth electoral rolls for the Barwon Statistical Division in south-eastern Australia (11). Age-stratification at baseline ensured that there were approximately 100 men for each 5-year age-group 20-24, 25-29, 30-34, 35-39, 40-44, 45-49, 50-54, 55-59, 60-64, and 65-69 years, and approximately 200 men for each of the age groups 70-79 and 80 years and older. Overall, 1540 men (aged 20-96 years) were

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recruited in 2001-2006 (with 67% participation) and 978 men (aged 25-98 years) were assessed approximately 5 years later, 2006-2011 (with 81% retention of eligible men). During the first phase, 94 men were aged <25 years and were not eligible for this analysis, 80 did not provide a whole body dual energy X-ray absorptiometry (DXA) scan and further 37 were excluded because they were too large for the DXA ($n = 31$) or had prostheses or implants. During the second phase, 62 men did not provide a whole body DXA scan and further 16 were excluded because they were too large or had prostheses or implants. Thus, 1329 men were included in phase 1 (2001-2006) and 900 in phase 2 (2006-2011). In the cross-sectional analysis of this study, the two phases have been considered as providing two cross-sectional datasets. BMI values were calculated for 50 of 117 excluded men in phase 1, and for 31 of the 78 excluded men from phase 2; there was no difference detected between the measured mean BMI values of the men excluded from each phase (mean BMI \pm SD, 36.1 ± 6.9 kg/m² for 2001-2006 vs 36.7 ± 6.8 kg/m² for 2006-2011, $P = 0.7$). We also performed a longitudinal analysis of 844 men who provided a whole body DXA scan at both visits. Most of the cohort (99%) was Caucasian. Further details of the study have been provided elsewhere (11). All participants gave written, informed consent. The Barwon Health Human Research Ethics Committee approved the study.

Measures of body composition

Body weight was recorded to the nearest 0.1 kg using electronic scales, standing height was measured to the nearest 0.001 m using a wall-mounted stadiometer and BMI expressed as weight/height² (kg/m²). Whole body scans were performed using DXA, initially using a Lunar DPX-L (software version 1.31; Lunar Madison, WI, USA) machine for 504 men at 2001-2006 assessment, and subsequently, a GE-Lunar Prodigy (Prodigy; GE Lunar, Madison, WI, USA) machine for 825 men at 2001-2006 when the DPX-L became outmoded. All 2006-2011 scans were performed using the Prodigy. Long-term stability of both machines was confirmed by routinely scanning an anthropometric phantom three times a week. There was no difference detected in median phantom BMC values measured by the prodigy DXA over three consecutive weeks mid-phase 1 and mid-phase 2 of the study (median values (IQR): 48.4 (48.1-48.7) vs 48.2 (48.0-48.3) g, $P = 0.2$). The whole body scans identified three components of body composition of interest: body fat mass, lean mass [a fat-free bone-free mass used as a surrogate measure of muscle mass that includes muscle, skin, connective tissue and the lean component of adipose tissue - water and protein (12)], and bone mass (identified as bone mineral content, BMC). Body fat mass, lean mass, and bone mass were expressed relative to the square of height (kg/m²). The terms %fat, %lean, and %bone represent body fat mass, lean mass, and bone mass expressed as percentages of the whole body mass from DXA (equivalent to the sum of body fat mass, lean mass, and bone mass). All clinical measures were performed by trained personnel.

Statistical analysis

In the cross-sectional analyses, differences in BMI, and the three components of body composition (body fat, lean, and bone) between the two time periods were determined using linear regression models. The variable of interest was the period of assessment (2001-2006 or 2006-2011); statistical models were adjusted for age and interaction terms were tested as effect modifiers and retained in the

TABLE 1 Subject characteristics for the two periods of assessment, 2001-2006 and 2006-2011

	2001-2006 n = 1329	2006-2011 n = 900
Age (year)	57.8 (42.6-74.0)	60.0 (46.4-73.5)
BMI (kg/m ²)	26.9 (\pm 3.6)	27.2 (\pm 3.7)
Fat mass (kg/m ²) ^a	6.95 (\pm 2.53)	7.63 (\pm 2.67)
Lean mass (kg/m ²) ^a	18.93 (\pm 1.70)	18.74 (\pm 1.69)
Bone mass (kg/m ²) ^a	1.04 (\pm 0.12)	1.02 (\pm 0.12)
%Fat ^b	25.2 (\pm 6.7)	27.2 (\pm 6.9)
%Lean ^b	70.9 (\pm 6.4)	69.0 (\pm 6.6)
%Bone ^b	3.9 (\pm 0.5)	3.8 (\pm 0.5)

Data are shown as median (interquartile range, IQR) or mean (\pm SD).

^aFat mass, lean mass, and bone mass expressed relative to the square of height (kg/m²).

^bMass of fat, lean, and bone expressed relative to whole body mass (sum of fat, lean, and bone).

model if $P < 0.05$. In contrast to our previous report of no difference in measures of mean femoral neck bone mineral density (BMD) when the two scanners were cross calibrated (13), systematic differences between such scanners have been reported (14). To address this issue, a sensitivity analysis was performed that excluded 504 men at baseline, who were measured on the Lunar DPX-L densitometer instead of the Lunar Prodigy densitometer. In longitudinal analyses, paired t -test was used to compare follow-up and baseline components of body composition (body fat, lean, and bone, expressed relative to height²), stratified by age. All analyses were performed using Minitab (version 15; Minitab, State College, PA).

Results

Cross-sectional analysis

Subject characteristics for the two time periods are shown in Table 1. Mean age-adjusted BMI increased 1.2%, from 26.9 kg/m² (95%CI 26.7-27.1) in 2001-2006, to 27.2 kg/m² (95%CI 27.0-27.4) in 2006-2011 ($P = 0.04$). Mean age-adjusted body fat mass increased by 9.0% from 6.98 kg/m² (95%CI 6.84-7.11) in 2001-2006, to 7.60 kg/m² (95%CI 7.44-7.77) in 2006-2011 ($P < 0.001$). In contrast, mean age-adjusted lean mass decreased 0.9%, from 18.92 kg/m² (95%CI 18.83-19.01) to 18.75 kg/m² (95%CI 18.64-18.86) ($P = 0.02$). Mean age-adjusted bone mass decreased 1.6%, from 1.041 kg/m² (95%CI 1.034-1.047), to 1.024 kg/m² (95%CI 1.016-1.032) ($P = 0.001$). Mean percentage changes in the three compartments of body composition over the 5-year period are shown in Figure 1.

There was a similar pattern of change when the components of body composition were expressed relative to whole body mass. Between 2001-2006 and 2006-2011, mean age-adjusted %fat increased from 23.4% (95%CI 22.6-24.2) to 25.2% (95%CI 24.9-25.6), mean age-adjusted %lean decreased from 72.6% (95%CI 71.8-73.4) to 70.9% (95%CI 70.5-71.2), and mean age-adjusted %bone decreased from 4.03% (95%CI 3.96-4.10) to 3.91% (95%CI 3.88-3.93); all $P < 0.001$.

A sensitivity analysis was performed that excluded 504 men at baseline, who were measured on the Lunar DPX-L densitometer instead

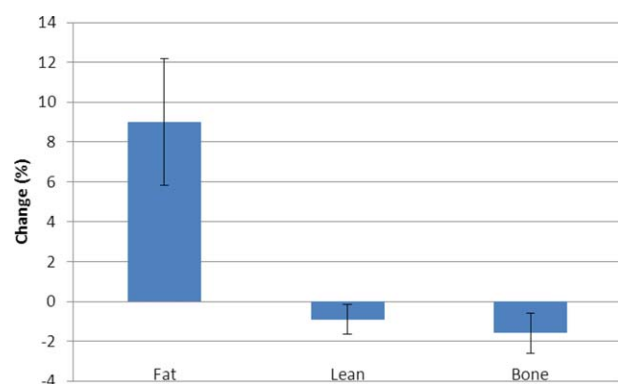


FIGURE 1 Mean percentage changes in body fat mass, lean mass, and bone mass, divided by the square of height (kg/m^2) that occurred between 2001-2006 and 2006-2011. The error bars represent the 95% confidence interval around the mean. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.

of the Lunar Prodigy densitometer. The following results showed the same pattern as seen in the full analysis. Between 2001-2006 and 2006-2011, mean age-adjusted %fat increased from 25.6% (95%CI 25.1-26.1) to 27.1% (95%CI 26.7-27.5), mean age-adjusted %lean decreased from 70.6% (95%CI 70.1-71.0) to 69.1% (95%CI 68.7-69.5), and mean age-adjusted %bone decreased from 3.83% (95%CI 3.80-3.87) to 3.78% (95%CI 3.75-3.82); all $P < 0.05$.

Longitudinal analysis

Mean differences in mass of body fat, lean, and bone between follow-up and baseline are presented in Table 2, for the whole group and stratified by age. A consistent pattern was observed of increased fat mass and decreased lean and bone across the age strata.

Discussion

We report an increase in BMI among men over a period of 5 years, which appears to have been driven by an increase in body fat; this pattern was evident when the increase in body fat mass was

considered in absolute terms and when body fat was expressed as a proportion of body weight. During the 5-year study period, both lean mass and bone mass decreased. In a longitudinal study of Swedish men for whom DXA scans were performed 1990-1991 and again 3-4 years later, body fat mass increased for all ages (20-87 years at baseline), whereas declines in lean mass and whole body BMD were evident and were more pronounced among older men (15). The temporal pattern of changes in body composition somewhat mirror our observations; however, direct comparison is difficult because the data relate to different periods of time.

The BMI thresholds commonly used for defining overweight and obesity are independent of age and sex (16). Consequently, any given value of BMI generally overestimates the amount of body fat in men who have muscular body builds and heavier bones, and underestimates body fat in the elderly (2). However, our data suggest that the observed temporal increase in BMI over 5 years does not reflect increases in musculature or skeletal mass.

The observed body composition changes are similar to those seen with ageing, yet they have occurred across the adult age spectrum. It would be interesting to speculate whether obesity is associated with accelerated ageing. We know that obesity increases the risk for other degenerative disorders, such as cardiovascular disease (3). A progressive age-related decline in the quantity, quality, and strength of skeletal muscle tissue leads to sarcopenia (6), which in the context of obesity, is referred to as sarcopenic obesity (7). This condition leads to general frailty and contributes substantially to the decreased independence and quality of life associated with ageing. Deterioration of the quantity and structure of bone similarly leads to age-related bone fragility (17) and increased rates of fracture (18).

In healthy individuals, increases in loading act through mechanoreceptors in muscle and bone to effect adaptive changes to better cope with increased body weight (19). If, however, the accumulation of excessive body fat and increased weight exceeds adaptive mechanisms, the musculoskeletal system may not adequately adapt. Furthermore, in sarcopenic obesity, infiltration of fat into muscle further compromises muscle quality, strength, and performance (7). A number of mechanisms could explain a link between increased body fat with declines in muscle and bone that are not limited to the elderly.

TABLE 2 Mean differences in mass of body fat, lean, and bone for assessments at follow-up (2006-2011) minus baseline (2001-2006)

Age (year)	Fat mass (kg/m^2)		Lean mass(kg/m^2)		Bone mass (kg/m^2)	
	Mean (SD)	P ^a	Mean (SD)	P ^a	Mean (SD)	p ^a
25-34 ($n = 103$)	0.67 (1.66)	<0.001	-0.12 (0.83)	0.15	-0.021 (0.052)	<0.001
35-44 ($n = 151$)	0.78 (1.03)	<0.001	-0.12 (0.59)	0.01	-0.026 (0.050)	<0.001
45-54 ($n = 160$)	0.80 (1.26)	<0.001	-0.31 (0.66)	<0.001	-0.038 (0.054)	<0.001
55-64 ($n = 159$)	0.95 (1.23)	<0.001	-0.31 (0.71)	<0.001	-0.035 (0.062)	<0.001
65-74 ($n = 148$)	0.76 (1.14)	<0.001	-0.52 (0.67)	<0.001	-0.026 (0.050)	<0.001
75+ ($n = 123$)	0.47 (1.25)	<0.001	-0.40 (0.65)	<0.001	-0.022 (0.049)	<0.001
All ($n=844$)	0.75 (1.26)	<0.001	-0.30 (0.69)	<0.001	-0.029 (0.054)	<0.001

Differences are expressed as mean (SD).

^aP-values from paired t -test.

Physical inactivity is a shared risk factor for obesity, muscle loss, and bone loss, and as such represents a lifestyle that could potentially connect the relative changes in body composition observed in this study. Low vitamin D levels observed in obesity (20) could also contribute to muscle weakness (21) and increased muscle fat (22), which further compromises muscle strength and increases insulin resistance (23). Vitamin D deficiency limits osteoblastogenesis and promotes adipocytogenesis (24). In vitamin D deficiency, mineralization of the skeleton is compromised (25) and BMD is reduced (20). Physical inactivity is associated with low levels of vitamin D (20), so as obesity increases in the population, it is likely that physical inactivity and low vitamin D levels may become more widespread, exacerbating the problem.

Another plausible link between obesity and musculoskeletal deterioration may be related to obesity as an inflammatory state. Fat cells in adipose tissue are metabolically active and produce pro-inflammatory cytokines, such as tumor necrosis factor α (TNF α) and interleukin (IL)-6, which contribute to an inflammatory condition (26). Circulating levels of C-reactive protein (CRP), a marker of systemic inflammation, increase with increasing BMI (27,28) suggesting that low-grade chronic inflammation is a potential mechanism for these associations. For example, TNF α is associated with reduced muscle mass, and strength (29) and loss of muscle fibers (30). TNF α is also one of the inflammatory cytokines that upregulates osteoclast differentiation and activity, promoting bone resorption (31). It is of interest that elevated serum high-sensitivity CRP has been identified as a marker of increased fracture risk (27). Furthermore, both adipocytes and osteoblasts arise from a common mesenchymal stem cell (32) and formation of each cell type is inversely linked; increased adipocyte differentiation and fat formation accompanies a decrease in osteoblast differentiation and bone formation (33). Pro-inflammatory cytokines mediate obesity-related insulin resistance, a condition exacerbated by loss of metabolically active muscle tissue and by fat accretion in muscle (23). Furthermore, leptin, an adipokine produced by fat cells, increases with obesity (34) and plays a role in regulating the metabolism of both skeletal muscle (35) and bone (36,37).

The main strengths of our study relate to the age-stratified random sampling technique used for recruitment, thus ensuring an even representation of ages across the adult age spectrum. Furthermore, we have identified body compositional changes using DXA rather than using change in BMI, which is limited to identifying changes in excess weight rather than discriminating changes in body fat, lean, and bone tissue that have occurred during the obesity epidemic. However, there are some limitations in our study. A potential recruitment and retention bias related to body composition cannot be excluded. While we established that there was no difference in the mean BMI for the men enrolled in the GOS but excluded from this analysis, no body composition data were available for nonparticipants. Longitudinal analysis of body composition data for men assessed at both baseline and follow-up confirmed the pattern of data analyzed cross-sectionally. The use of a bone densitometer for measuring body composition precluded the largest individuals as the DXA has a maximum safety load limit (120 kg) and the bed dimensions do not accommodate very large individuals. In the absence of cross-calibration data between the Lunar DPX-L and Prodigy densitometers, a sensitivity analysis that limited comparison of individuals measured on one machine alone showed similar findings to the full analysis; however, we cannot exclude the possibility of a cross-calibration difference between the two machines that might depend

on BMI (38). Furthermore, differentiation between the body fat, lean, and bone compartments by the DXA may have been obscured as excess adipose tissue increasingly causes artefactual changes in the readings and the lean mass measure only approximates muscle mass; we did not assess muscle strength or performance. Finally, given that the sample was male and essentially white, our findings may not be generalizable to women or to other ethnicities.

In conclusion, we report that over a period of 5 years, an observed increase in BMI appears to have been driven by an increase in body fat mass and that this has been accompanied by a decline in both lean mass and bone mass. This may have implications for future development of bone fragility, sarcopenia, and sarcopenic obesity in the male population. The challenge is to identify public health strategies that are effective in modifying the current obesogenic environment, in an attempt to counteract these detrimental alterations to body composition. **O**

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