Sarcopenic obesity is associated with osteopenia among Japanese elderly women: A cross-sectional study from comprehensive health checkups

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ABSTRACT

Objective. The aim of this study was to assess the relationship between sarcopenic obesity (SO) and osteopenia among Japanese elderly women.

Design. Cross-sectional observational study.

Setting. Comprehensive-health checkup center.

Participants. A total of 126 women (mean age 72.5 ± 5.4 years) who underwent comprehensive health checkups and examinations both of whole-body composition and bone mineral density using dual-energy X-ray absorptiometry were enrolled. Sarcopenia was defined as a height-adjusted skeletal muscle mass <5.4 kg/m2. Obesity was defined as a total-body fat percentage ≥30%. Osteopenia was defined as a percentage of young adult mean <80%.

Main outcome and measures. Multivariate logistic regression analyses were performed to identify the risk factors for osteopenia associated with SO.

Results. The prevalence of sarcopenia, obesity, and SO were 17%, 36%, and 16%, respectively. More than half of the participants were regarded as having osteopenia. The prevalence of osteopenia was higher in sarcopenia and SO subjects and lower in obese subjects than in standard phenotype. Subjects with osteopenia showed characteristics of sarcopenia, i.e. a lower body mass index, lower skeletal muscle mass, and lower fat mass. Multivariate logistic regression analyses revealed that SO subjects were significantly associated with the prevalence of osteopenia (odds ratio and 95% confidence interval: 4.26, 1.10–16.4) after adjustment for age and visceral fat area. The association remained marginal after additive adjustments for smoking, drinking, and physical activity (odds ratio and 95% confidence interval: 3.77, 0.92–15.4).

Conclusions. SO was significantly associated with the prevalence of osteopenia among Japanese elderly women.

Key words osteopenia, sarcopenia, obesity, elderly

Introduction

Japan is known as a super-aged society, with an elderly population ratio of 26.7%, and the average life expectancy reached 80.75 years for men and 86.99 years for women in 20151, 2. Under these circumstances, the burden of benefits of social security, such as medical service and long-term care insurance, is increasing3. Therefore, it is vitally important to the national interest for individuals to maintain good health and avoid disability in their old age. According to the annual report of the Cabinet Office4, frailty and osteoarthropathy, such as osteoarthritis, osteoporosis, and fracture, are major causes of disability, especially for elderly women. Thus, there is no doubt that maintaining one’s locomotive organ function is a pivotal strategy for ensuring autonomy in old age.

Aging is a dominant risk factor for a deteriorated locomotive function. The loss of muscle mass and function that emerges during the aging process is known as sarcopenia5, and gaining fat mass leads to obesity. The accumulation of ectopic fat, such as in visceral fat tissue, is a particularly distinctive feature of the elderly6. Recently, the coexistence of sarcopenia and obesity, a condition known as sarcopenic obesity (SO)7, has received focus among researchers because of its strong impact on not only the functional decline8 but also the prevalence of cardiovascular disease9, metabolic disorders10, 11, and mortality12.

Osteopenia is another body compositional change that occurs with age. The peak bone mass has generally been developed by one’s 20s and is maintained until one’s 40s, after which it gradually declines13. Menopause causes a steep decline in the bone mineral density (BMD), so postmenopausal women are more vulnerable than premenopausal women and men to developing osteoporosis14. A recent population-based epidemiological study for bone and joint diseases among the Japanese revealed that the prevalence of osteoporosis among Japanese adults ≥40 of age
was 12.8 million, with roughly three-quarters of those being women. From a pathophysiological aspect, bone, muscle, and fat tissues are interconnected in the human body via the complicated endocrine system or common multipotent mesenchymal stem cells. A combined-body compositional phenotype that encompasses osteopenia, sarcopenia, and obesity was recently introduced, termed osteosarcopenic obesity. However, osteopenia with obesity has received less attention than SO, probably because obese individuals in general tend to have a high bone mass and better bone health.

We performed a cross-sectional study to evaluate the relationship between SO and osteopenia among Japanese elderly women in the field of comprehensive health checkups.

Materials and Methods

Subjects

Women ≥65 years of age who underwent comprehensive health checkups at the Center for Preventive Medicine, Keio University Hospital, from August 1, 2012, to July 31, 2015, were enrolled. Those who did not undergo an examination for the whole-body composition and BMD by dual-energy X-ray absorptiometry (DXA) were excluded. Individuals who were taking medicine for osteoporosis, such as bisphosphonates and vitamin D agents, or steroids and those who had been suffering from rheumatism, thyroid dysfunction, and malignant diseases were also excluded. In total, 126 subjects (mean age, 72.5 ± 5.4 years) were eligible for inclusion in this study.

Ethical considerations

This study was performed with approval from the Ethics Committee of Keio University School of Medicine (approval number: 20160363). Informed consent was waved because of the retrospective study design, and a means to opt out was provided instead.

Anthropometry, body composition and BMD measurements

The body height and body weight were measured with the subjects wearing light clothes without shoes. The body mass index (BMI) was calculated as the body weight (kg) divided by the squared body height (m²). The appendicular skeletal muscle mass (ASM) and total-body fat mass (FM) were measured using DXA (LUNAR PRODIGY series X-ray bone densitometer; GE Healthcare Japan Corporation, Tokyo, Japan). The skeletal muscle mass index (SMI) was calculated as the ASM (kg) divided by the squared body height (m²). The percentage of FM (%FM) was calculated as the FM (kg) divided by the body weight (kg) multiplied by 100. The BMD was also measured by DXA at two sites—the lumbar spine (L1~L4) and femoral neck—and the percentage of young adult mean (%YAM) for each site was calculated automatically. The lower %YAM was used for the analysis. As mentioned above, we measured the BMD at two sites and used the lower %YAM for the analysis. Individuals with a lower %YAM <80% were defined as having osteopenia.

Blood chemistry measurements

Blood samples were collected after overnight fasting and immediately examined using an automatic biochemical analyzer (LABOSPECT008; Hitachi High-Technologies Corporation, Tokyo, Japan) at the central laboratory.

Other clinical data

Clinical data were extracted from the results of the comprehensive health checkups and included data related to the age, sex, fasting plasma glucose (FPG) level, hemoglobin A1c (HbA1c) level, total cholesterol level, triglycerides (TG) level, high-density lipoprotein cholesterol (HDL-C) level, low-density lipoprotein cholesterol (LDL-C) level, and high-sensitivity C-reactive protein (hsCRP) level. Life-style habits, such as current smoking, current drinking, and regular exercise, as well medical histories were obtained from self-reported questionnaires. Drinking habit was defined as “consumption of more than 40 g of alcohol at least 3 times a week,” and a regular exercise habit was evaluated by 2 questions: (1) “Do you perform daily walking activity for at least 1 hour?”, (2) “Do you perform daily exercise with mild sweating for more than 30 minutes at least twice a week?” Those who did not respond ‘yes’ to both questions were defined as having low physical activity.

Definition of sarcopenia, obesity, and SO

According to the Asian Working Group for Sarcopenia criteria, we used the SMI cut-off point of <5.4 kg/m² for women to diagnose sarcopenia. Regarding obesity, we used the %FM cut-off point of ≥30% for women. Participants who met the criteria for both definitions were defined as having SO. According to these definitions, participants were classified into four phenotypes of body composition: standard, sarcopenia (without obesity), obesity (without sarcopenia), and SO (Figure 1).

Definition of osteopenia

As mentioned above, we measured the BMD at two sites and used the lower %YAM for the analysis. Individuals with a lower %YAM <80% were defined as having osteopenia.

Statistical analyses

Continuous variables were expressed as the mean ± standard deviation, and categorical variables were presented as counts and percentages. The chi-squared test was used to compare the

![Fig. 1](image-url)
categorical variables. Comparisons between the normal BMD group and the osteopenia group were analyzed using the unpaired Student’s t-test. Multivariate logistic regression analyses were performed to identify the risk factors for osteopenia associated with SO. The following explanatory variables were included in the models: age, VFA, smoking habits (0,1), drinking habits (0,1), and regular exercise habits (0,1). A value of \( p < 0.05 \) (two sided) was considered significant. Data were analyzed using the IBM SPSS Statistics software program, version 23 for Windows (IBM Japan, Tokyo, Japan).

Results

Characteristics of the participants

The baseline characteristics of the participants are shown in Table 1. Regarding the body shape, the mean BMI and the mean VFA were 21.6 kg/m\(^2\) and 80.4 cm\(^2\), respectively, and the mean %FM was 30.5%. The mean %YAM was 78.6%, and the mean SMI was 5.73 kg/m\(^2\). Osteopenia was noted in 54% of the participants. The clinical laboratory data, including the blood pressure, were approximately within the normal range. About 30% of the participants had received medications for hypertension or dyslipidemia, and 5% had received medications for type 2 diabetes mellitus. Current smokers were scarce, and almost half of the participants had no regular exercise habits, being defined as having low physical activity.

Regarding the body type, 31% of the participants were classified as having the standard body phenotype, 36% were obese, 17% had sarcopenia, and 16% had SO. Among the four phenotypes of body composition, the prevalence of osteopenia was high in the sarcopenia and SO subjects and low in the obese subjects (prevalence of osteopenia in standard body phenotype, sarcopenia, obesity and SO: 56%, 73%, 33%, and 75%, respectively; chi-squared test, \( p=0.002 \) (Table 2).

We compared the clinical parameters and indices of body composition between the normal BMD group and the osteopenia group. As expected, the osteopenia group showed characteristics of sarcopenia, having a lower BMI, lower VFA, lower SMI, and lower %FM (Table 3).

Multivariate logistic regression analyses

To determine the relationship between the body composition phenotype and the prevalence of osteopenia, logistic regression analyses were performed. As shown in Table 4A, subjects with obesity were associated with a decreased risk of osteopenia in the univariate analyses (crude odds ratio [OR] and 95% confidence interval [CI] for obesity: 0.39, 0.16–0.94). However, in the age- and VFA-adjusted model (Model 1), the OR for obese subjects was not significant, whereas the SO subjects showed a significant association with the prevalence of osteopenia (OR and 95% CI for SO: 4.26, 1.10–16.4). Furthermore, after additive adjustments for lifestyle habits (Model 2), only the SO subjects showed a marginally positive association with the prevalence of osteopenia (OR and 95% CI for SO: 3.77, 0.92–15.4) (Table 4B).

| Table 1 Characteristics of participants | Total (n=126) |
|-----------------------------|-------------|
| Age (years)                | 72.5 ± 5.4  |
| BMI (kg/m\(^2\))           | 21.6 ± 3.9  |
| VFA (cm\(^2\))             | 80.4 ± 46.5 |
| Systolic blood pressure (mmHg) | 122.5 ± 19.8 |
| Diastolic blood pressure (mmHg) | 74.3 ± 10.6 |
| FPG (mg/dL)                | 104.2 ± 16.8|
| HbA1c (%)                  | 5.8 ± 0.4   |
| HOMA-R                     | 1.4 ± 1.3   |
| TC (mg/dL)                 | 215.9 ± 34.4|
| TG (mg/dL)                 | 85.6 ± 40.6 |
| HDL-C (mg/dL)              | 65.7 ± 13.5 |
| LDL-C (mg/dL)              | 116.7 ± 29.0|
| hsCRP (mg/dL)              | 0.13 ± 0.39 |
| SMI (kg/m\(^2\))           | 5.73 ± 0.60 |
| %FM (%)                    | 30.5 ± 8.0  |
| %YAM (%)                   | 78.6 ± 12.6 |
| Osteopenia (n [%])         | 68 (54.0)   |
| Current smoker (n [%])     | 4 (3.2)     |
| Current drinker (n [%])    | 39 (31.0)   |
| Low physical activity (n [%]) | 57 (45.2) |
| Comorbidities (n [%])      |             |
| Hypertension               | 38 (30.2)   |
| Dyslipidemia               | 35 (27.8)   |
| Diabetes mellitus          | 7 (5.6)     |

All data are expressed as mean ± standard deviation. BMI, body mass index; VFA, visceral fat area; FPG, fasting plasma glucose; HbA1c, hemoglobin A1c; HOMA-R, homeostasis model assessment of insulin resistance; TC, total cholesterol; TG, triglycerides; HDL-C, high-density lipoprotein cholesterol; LDL-C, low-density lipoprotein cholesterol; hsCRP, high-sensitivity C-reactive protein; SMI, skeletal muscle mass index; FM, total-body fat mass; YAM, young adult mean.

| Table 2 Body composition phenotypes and the prevalence of osteopenia | Total (n=126) |
|-------------------------------------------------------------|-------------|
| Body composition phenotypes (n [%])                        |             |
| Standard                                                   | 39 (31.0)   |
| Sarcopenia                                                | 22 (17.5)   |
| Obesity                                                   | 45 (35.7)   |
| Sarcopenic obesity                                        | 20 (15.9)   |
| The prevalence of osteopenia (n [%])                      |             |
| Standard                                                  | 22 (56.4)   |
| Sarcopenia                                                | 16 (72.7)   |
| Obesity                                                   | 15 (33.3)   |
| Sarcopenic obesity                                        | 15 (75.0)   |

* \( \chi^2 \)-test.
### Table 3: A comparison of the clinical parameters between the normal bone mineral density group and the osteopenia group

| Parameter                          | Normal BMD (n=58) | Osteopenia (n=68) | P-valuea |
|------------------------------------|-------------------|-------------------|----------|
| Age (years)                        | 72.0 ± 5.1        | 73.0 ± 5.6        | 0.284    |
| BMI (kg/m²)                        | 23.4 ± 4.4        | 20.1 ± 2.5        | <0.001*  |
| VFA (cm²)                          | 95.6 ± 53.1       | 67.4 ± 35.6       | <0.001*  |
| Systolic blood pressure (mmHg)     | 126.3 ± 19.6      | 119.2 ± 19.5      | 0.046*   |
| Diastolic blood pressure (mmHg)    | 75.5 ± 10.4       | 73.3 ± 10.9       | 0.242    |
| FPG (mg/dL)                        | 105.2 ± 12.3      | 103.3 ± 20.0      | 0.548    |
| HbA1c (%)                          | 5.8 ± 0.4         | 5.8 ± 0.5         | 0.723    |
| HOMA-R                             | 1.63 ± 1.29       | 1.17 ± 1.21       | 0.043*   |
| TC (mg/dL)                         | 216.4 ± 28.6      | 215.5 ± 38.9      | 0.887    |
| TG (mg/dL)                         | 89.0 ± 46.1       | 82.7 ± 35.4       | 0.381    |
| HDL-C (mg/dL)                      | 65.0 ± 13.0       | 66.2 ± 14.0       | 0.619    |
| LDL-C (mg/dL)                      | 117.0 ± 23.8      | 116.5 ± 33.0      | 0.912    |
| hsCRP (mg/dL)                      | 0.13 ± 0.28       | 0.12 ± 0.47       | 0.887    |
| SMI (kg/m²)                        | 5.96 ± 0.60       | 5.53 ± 0.53       | <0.001*  |
| %FM (%)                            | 33.2 ± 8.3        | 28.2 ± 7.0        | <0.001*  |
| %YAM (%)                           | 89.9 ± 7.9        | 68.9 ± 6.3        | <0.001*  |
| Current smoker (n [%])b            | 2 (3.4)           | 2 (2.9)           | 0.871    |
| Current drinker (n [%])b           | 22 (37.9)         | 17 (25.0)         | 0.118    |
| Low physical activity (n [%])b     | 24 (41.4)         | 33 (48.5)         | 0.422    |

All data are expressed as mean ± standard deviation. *: P<0.05. 
* Unpaired Students’ t-test (normal BMD vs. osteopenia). † χ²-test.
BMD, bone mineral density; BMI, body mass index; VFA, visceral fat area; FPG, fasting plasma glucose; HbA1c, hemoglobin A1c; HOMA-R, homeostasis model assessment of insulin resistance; TC, total cholesterol; TG, triglycerides; HDL-C, high-density lipoprotein cholesterol; LDL-C, low-density lipoprotein cholesterol; hsCRP, high-sensitivity C-reactive protein; SMI, skeletal muscle mass index; FM, total-body fat mass; YAM, young adult mean.

### Table 4A: The relationship between body composition phenotypes and osteopenia: Univariate logistic regression analyses

|                      | Total (n=126) |          |          |
|----------------------|--------------|----------|----------|
|                      | Crude OR     | 95% CI   |          |
| Standard             | 1.00         | ref      |          |
| Sarcopenia           | 2.06         | 0.66–6.39|          |
| Obesity              | 0.39         | 0.16–0.94*|          |
| Sarcopenic obesity   | 2.32         | 0.70–7.65|          |

Univariate regression analyses were performed to assess the relationship between the body composition phenotypes and the risk of osteopenia. The prevalence of osteopenia was analyzed as an independent variable, and all four phenotypes of body composition were included as dependent variables. OR, odds ratio; 95% CI, 95% confidence interval. *: P<0.05.

### Table 4B: The relationship between body composition phenotypes and osteopenia: Multivariate logistic regression analyses

|                      | Total (n=126) |          |          |
|----------------------|--------------|----------|----------|
|                      | Model 1 OR   | 95% CI   | Model 2 OR | 95% CI |
| Standard             | 1.00         | ref      | 1.00     | ref    |
| Sarcopenia           | 1.99         | 0.63–6.34| 2.00     | 0.63–6.37|
| Obesity              | 0.89         | 0.29–2.67| 0.83     | 0.27–2.56|
| Sarcopenic obesity   | 4.26         | 1.10–16.4*| 3.77     | 0.92–15.4 # |

Multivariate logistic regression analyses were performed to assess the relationship between body composition phenotypes and osteopenia. The prevalence of osteopenia was analyzed as an independent variable, and all four phenotypes of body composition were included as dependent variables. Model 1 is adjusted by age and visceral fat area. Model 2 is adjusted by all variables including Model 1+smoking, drinking, and regular exercise habits. OR, odds ratio; 95% CI, 95% confidence interval. *: P<0.05, #: P<0.10.
Discussion

In the present study, we evaluated the impact of age-related changes in the body composition on the BMD in Japanese elderly women and found that SO had a strong association with the prevalence of osteopenia.

Age-related changes in the body composition are characterized by a loss of muscle mass and gain of fat mass, with the former known as sarcopenia and the latter as obesity. Recently, the coexistence of sarcopenia and obesity has been observed and termed SO. Although the diagnostic criteria have not yet been established, research interest in SO has been growing, and several studies have described a relationship of SO with disability, cardiovascular disease, metabolic disorder, and mortality.

Another concern associated with age-related changes in the body composition is the loss of bone mass, leading to osteopenia or osteoporosis. Osteopenia and osteoporosis increase the susceptibility to fragile fracture, which leads to poor outcomes, such as disability, a diminished quality of life, and high mortality. Since approximately one-third of cases of disability in elderly Japanese women are due to osteoarthropathy, maintaining bone health and preventing fracture is quite important for ensuring their healthy old life.

Since mechanical stress is known to have a positive effect on maintaining bone health, it is natural to hypothesize that obese individuals would have less difficulty maintaining their BMD, while individuals with sarcopenia are regarded as high-risk subjects for osteopenia or osteoporosis. However, the present study revealed that the impact of SO on osteopenia was greater than that of sarcopenia alone. Chung et al. performed a population-based survey with a large number of Korean men and women ≥50 years of age and evaluated the association between SO and the BMD. They obtained results similar to our own, finding that SO was closely associated with the development of osteoporosis among both men and women.

The combination of SO and impaired bone health is a newly identified phenotype called osteosarcopenic obesity. Although the pathophysiological mechanism underlying this triad is complex, adipokines secreted from adipocytes play a partial role. Visceral fat tissue is known to act as an endocrine organ and produces pro-inflammatory adipokines, such as interleukin-6 (IL-6) and tumor necrosis factor-α (TNF-α), which then promotes low-grade chronic inflammation. Sustained low-grade chronic inflammation causes the disarrangement of bone, muscle, and fat tissues simultaneously. Leptin, another adipokine, also acts as a strong proinflammatory stimulator and may exacerbate osteopenia and sarcopenia. For example, proinflammatory cytokines in obesity may promote osteoclast activity and bone resorption by modifying the receptor activator of the NF-κB (RANK)/RANKL/osteoprotegerin pathway. Furthermore, the excess secretion of leptin and/or decreased production of adiponectin by adipocytes in obesity may either directly affect bone formation or indirectly affect bone resorption through the upregulation of proinflammatory cytokine production.

Similarly, interactions between muscle and adipokines have been postulated. IL-6 and TNF-α are associated with both increased fat mass and decreased muscle mass. Increased leptin may lead to leptin resistance, and leptin resistance may cause a reduction in fatty acid oxidation in muscles, which contributes to ectopic fat deposition. Ectopic intramuscular fat infiltration may affect the muscle quality.

The positive association between SO and osteopenia presented in this study was significant after adjustment for VFA, suggesting that other ectopic adipocytes, such as intra-muscle fat tissue and bone marrow adipose tissue, act as endocrine organs and affect the metabolism of the bone-muscle-fat axis. Obesity may increase the fat accumulation in bone marrow, and ectopic bone marrow adipocytes decrease the osteoblast differentiation and/or myocyte differentiation, as adipocytes, myocytes, and osteoblasts are derived from common mesenchymal stem cells (MSCs). Therefore, under adverse microenvironments, MSC lineages are deregulated, giving rise to unfavorable consequences, such as excess fat mass, loss of muscle mass, and loss of bone mass, as a result osteosarcopenic obesity.

Clinically, it is important to identify individuals with osteosarcopenic obesity, as osteosarcopenic obesity is significantly related to functional decline and frailty in elderly women compared to their counterparts without osteosarcopenic obesity. When conducting comprehensive health checkups in the elderly, it is important to assess the body composition and BMD and evaluate the risk factors for disability and frailty. Furthermore, exploring the underlying conditions that result in the deteriorated health of elderly individuals, such as malnutrition, a sedentary lifestyle, poor social support, and depression, is also helpful for preventing frailty and a loss of independence. We should try to provide health checkups tailored to the elderly to detect early stages of frailty.

Several limitations associated with the present study warrant mention. First, regarding the definition of sarcopenia, we lacked data on the muscle function, such as the hand grip power or walking speed. Assessing not only the body composition but also the muscle function in comprehensive health checkups is essential in super-aged societies like Japan. Second, since participants in this study were recruited from among individuals who underwent comprehensive health checkups, they might have been more health conscious than the general population, which may have led to selection bias. Third, because of the cross-sectional nature of the study, we were unable to detect a causal relationship between SO and osteopenia. A four-year observational cohort study evaluated whether osteoporosis contributed to the subsequent development of sarcopenia or vice versa and found that the presence of osteoporosis significantly increased the risk of sarcopenia occurrence (approximately three-fold) after adjustment for plausible confounders. A significant reciprocal relationship was not observed. Since those authors did not evaluate the fat mass, the causal relationship between SO and osteopenia remained unclear. Fortunately, we have opportunities to collect data from individuals who undergo comprehensive health checkups annually, so we will continue our research to assess the causal relationship between SO and osteopenia from a longitudinal perspective in the future.
future.

In conclusion, the present cross-sectional study assessed the relationship between the age-related change in the body composition and the prevalence of osteopenia among Japanese elderly women who had completed comprehensive health checkups. SO was found to be associated with the prevalence of osteopenia, independently of age and VFA.

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REFERENCES

1) Cabinet Office, Government of Japan. Annual Report on the Aging Society: 2016. (Accessed March 20, 2018, at http://www8.cao.go.jp/kourei/whitepaper/w-2016/gaiyou/pdf/1s1s.pdf) (in Japanese).
2) Ministry of Health, Labour, and Welfare. Abridged life tables for Japan in 2015. (Accessed March 20, 2018, at http://www.mhlw.go.jp/toukei/saikin/hw/life/22/11/dl/22h_02.pdf) (in Japanese).
3) Ministry of Health, Labour, and Welfare. Annual health, labour, and welfare report 2017. (Accessed March 20, 2018, at http://www.mhlw.go.jp/wp/hakusyo/kousei/17-1/dl/gaiyou.pdf) (in Japanese).
4) Cabinet Office, Government of Japan. Annual Report on the Aging Society: 2002. P.98, Fig. 2-2-32. (Accessed March 20, 2018, at http://www8.cao.go.jp/kourei/whitepaper/w-2002/pdf/13-2-2.pdf) (in Japanese).
5) Rosenberg IH. Sarcopenia: origins and clinical relevance. J Nutr 1997; 127: 990S-991S.
6) Hunter GR, Gower BA, Kane BL. Age related shift in visceral fat. Int J Body Compos Res 2010; 8: 103-8.
7) Zamboni M, Mazzali F, Fantin F, Rossi A, Di Francesco V. Sarcopenic obesity: a new category of obesity in the elderly. Nutr Metab Cardiovasc Dis 2008; 18: 388-95.
8) Hirani V, Naganathan V, Blyth F, Le Couteur DG, Seibel MJ, Wait LM, et al. Longitudinal associations between body composition, sarcopenic obesity and outcomes of frailty, disability, institutionalization and mortality in community-dwelling older men: The Concord Health and Ageing in Men Project. Age Ageing 2016; 0: 1-8.
9) Stephen WC, Janssen I. Sarcopenic obesity and cardiovascular disease risk in the elderly. J Nutr Health Aging 2009; 13: 460-6.
10) Lim S, Kim JH, Yoon JW, Kang SM, Choi SH, Park YJ, et al. Sarcopenic obesity: prevalence and association with metabolic syndrome in the Korean Longitudinal Study on Health and Aging (KLoSHA). Diabetes Care 2010; 33: 1652-4.
11) Takayama M, Azuma K, Hayashi K, Shimizu-Hirota R, Makino K, Bessho R, et al. Relationship between sarcopenic obesity and metabolic syndrome among Japanese elderly who underwent a comprehensive health checkup. HEP 2017; 44: 1-7.
12) Atkins JL, Whincup PH, Morris RW, Lennon LT, Papacosta O, Wannamethee G. Sarcopenic obesity and risk of cardiovascular disease and mortality: a population-based cohort study of older men. J Am Geriatr Soc 2014; 62: 253-60.
13) Warming L, Hassager C, Christiansen C. Changes in bone mineral density with age in men and women: a longitudinal study. Osteoporos Int 2002; 13: 105-12.
14) Yoshimura N, Nakamura K. Epidemiology of locomotive organ disorders and symptoms: an estimation using the population-based cohorts in Japan. Clin Rev Bone Miner Metab 2016; 14: 68-73.
15) Cianferotti L, Brandi ML. Muscle-bone interactions: basic and clinical aspects. Endocrine 2014; 45: 165-77.
16) Reid IR. Relationships between fat and bone. Osteoporos Int 2008; 19: 595-606.
17) Ilich JZ, Kelly OJ, Inglis JE, Panton LB, Duque G, Ormsbee MJ. Interrelationship among muscle, fat, and bone: connecting the dots on cellular, hormonal, and whole body levels. Aging Research Reviews 2014; 15: 51-60.
18) Chen LK, Liu LK, Woo J, Assantachai P, Ayuseung TW, Bahyah KS, et al. Sarcopenia in Asia: consensus report of the Asian Working Group for Sarcopenia. J Am Med Dir Assoc 2014; 15: 95-101.
19) Ministry of Health, Labour, and Welfare. Obesity and Health. (Accessed March 20, 2018, at https://www.e-healthnet.mhlw.go.jp/information/food/e-02-001.html) (in Japanese).
20) Roth T, Kammerlander C, Gosch M, Lugter TJ, Blauth M. Outcome in geriatric fracture patients and how it can be improved. Osteoporos Int 2010; 21(Suppl 4): S615-S619.
21) Felson DT, Zhang Y, Hannan MT, Anderson JJ. Effects of weight and body mass index on bone mineral density in men and women: the Framingham study. J Bone Miner Res 1993; 8: 567-73.
22) 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: 77-84.
23) Jafari Nasab P, Inglis JE, Reilly W, Kelly OJ, Ilich JZ. Aging human body: changes in bone, muscle and body fat with consequent changes in nutrient intake. J Endocrinol 2017; 234: R37-R51.
24) Faggioni R, Feingold KR, Grunfeld C. Leptin regulation of the immune response and the immunodeficiency of malnutrition. FASEB J 2001; 15: 2565-71.
25) Cao JJ. Effects of obesity on bone metabolism. J Orthop Surg Res 2011; 6: 30.
26) Cesari M, Kritchevsky SB, Baumgartner RN, Atkinson HH, Penninx B, Lenchik L, et al. Sarcopenia, obesity, and inflammation — results from the trial of angiotensin converting enzyme inhibition and novel cardiovascular risk factors study. Am J Clin Nutr 2005; 82: 428-35.
27) Unger RH. Longevity, lipotoxicity and leptin: the adipocyte defense against fasting and famine. Biochimie 2005; 87: 57-64.
28) Hamrick MW, McGee-Lawrence ME, Frechette DM. Fatty infiltration of skeletal muscle: mechanisms and comparisons with bone marrow adiposity. Front Endocrinol (Lausanne) 2016; 7: 69.
29) Ilich JZ, Inglis JE, Kelly OJ, McGill DL. Osteosarcopenic obesity is associated with reduced handgrip strength, walking abilities, and balance in postmenopausal women. Osteoporos Int 2015; 26: 2587-95.
30) Szlejf C, Parra-Rodriguez L, Rosas-Carrasco O. Osteosarcopenic obesity: prevalence and relation with frailty and physical performance in middle-aged and older women. JAMDA 2017; 733: 1-e5.
31) Yoshimura N, Muraki S, Oka H, lIdaka T, Kodama R, Kawaguchi H, et al. Is osteoporosis a predictor for future sarcopenia or vice versa? Four-year observations between the second and third ROAD studies surveys. Osteoporos Int 2017; 28: 189-99.