

Body composition and osteoporotic fracture using anthropometric prediction equations to assess muscle and fat masses

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Abstract

Background Obesity is protective of bone health; however, abdominal obesity is associated with a higher fracture risk. Little is known about whether body composition protects or adversely affects osteoporotic fractures because of practical issues regarding assessment tools. This study aimed to evaluate the association of predicted body composition with fracture risk to determine the distinctive and differing effects of muscle or fat mass on bone health outcomes in the general population.

Methods This population-based, longitudinal cohort study used 2009–2010 Korean National Health Insurance Service data and follow-up data from 1 January 2011 to 31 December 2013, to determine the incidence of osteoporotic fracture (total, spine, and non-spine) defined using the International Classification of Diseases, Tenth Revision codes. The study participants were aged ≥ 50 years (men, 158 426; women, 131 587). The predicted lean body mass index (pLBMI), appendicular skeletal muscle index (pASMI), and body fat mass index (pBFMI) were used to assess body composition, using anthropometric prediction equations.

Results Over a 3 year follow-up, we identified 2350 and 6175 fractures in men and women, respectively. The mean age of the participants was 60.2 ± 8.3 and 60.7 ± 8.4 years in men and women, respectively. In a multivariable-adjusted Cox proportional hazards regression model, increasing pLBMI or pASMI was significantly associated with a decreased risk of total fractures in men and women. When comparing individuals in the lowest pLBMI and pASMI (reference groups), men with the highest pLBMI and pASMI had adjusted hazard ratios of 0.63 [95% confidence interval (CI) 0.47–0.83] and 0.62 (95% CI 0.47–0.82), and women with the highest pLBMI and pASMI had adjusted hazard ratios of 0.72 (95% CI 0.60–0.85) and 0.71 (95% CI 0.60–0.85), respectively, for total fractures. The pBFMI had no significant association with total fractures in men or women. Regarding sex-specific or site-specific differences, the protective effects of the pLBMI and pASMI on fractures were greater in men and reduced the risk of spinal fractures. An increased pBFMI was associated with an increased risk of spinal fractures in women.

Conclusions An increased pLBMI or pASMI was significantly associated with decreased total osteoporotic fracture risk; however, the pBFMI showed no statistically significant association. Muscle mass was more important than fat mass in preventing future osteoporotic fractures based on anthropometric prediction equations.

Keywords Body composition; Skeletal muscle; Body fat distribution; Osteoporotic fractures; Predictive value of tests

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Introduction

Osteoporotic fractures are a common public health issue. The incidence of osteoporosis-associated fractures is expected to rise continuously in line with predicted increases in average life expectancy and ageing populations.¹ It is estimated that ~3 million cases of osteoporotic fractures will occur annually worldwide by 2025.² Fractures are a cause of disability and a major contributor to the economic burden on healthcare systems. Moreover, vertebral and hip fractures are associated with high morbidity and mortality rates.³

Body mass index (BMI) is a reliable clinical parameter for predicting obesity, which is a well-established beneficial factor in relation to bone mass due to the positive influence of mechanical loading of weight on bone structure. Although BMI is commonly and easily used in clinical settings, it has significant limitations. BMI does not compartmentalize body weight, which means that it cannot differentiate between lean and fat mass⁴; hence, it is difficult to determine the distinctive and differing effects of muscle mass and fat mass on bone health outcomes. Recent publications have focused on emerging evidence regarding body composition related to bone health. Several studies have demonstrated the independent effect of muscle or fat component on bone mineral density (BMD).^{5,6} However, the association between fat mass and fractures is controversial, with studies reporting either protective or negative findings.^{7–9} Previous studies have reported that muscle mass has a greater effect on bone than fat mass.^{10,11} However, the interaction between muscle mass or fat mass and fractures remains unclear, and little is known about the relationship between body composition and osteoporotic fractures.

Existing assessment tools for body composition, such as dual-energy X-ray absorptiometry (DXA), bioelectrical impedance analysis, and medical imaging, including computed tomography and magnetic resonance imaging, are not useful in the practical setting as these tools require expensive and sophisticated technologies¹²; thus, prediction equations for body composition have been developed using anthropometric measures.¹³

The purpose of this study was to investigate the independent roles of muscle and fat mass separately on osteoporotic fracture risks using anthropometric prediction equations to estimate body composition in a 3 year follow-up cohort study involving Korean adults aged ≥ 50 years.

Methods

Study participants and data source

This study was performed by utilizing the database of the National Health Insurance Service-Health Screening

(NHIS-HEALS), which includes a cohort of individuals who are registered in a health screening programme conducted by the National Health Insurance Service (NHIS) in South Korea, and the individuals participating in this programme were followed up from 2002 to 2013. The NHIS-HEALS includes a national representative random sample of 514 866 individuals (aged between 40 and 79 years), which covers ~97% of the entire Korean population and all types of insurance claims data. This database contains insurance eligibility data, sociodemographic information, laboratory measurements, medical treatments, medical care institutions, clinic visits, hospitalizations, diagnostic codes, medication prescriptions, and mortality information, such as the cause and date of death. The NHIS-HEALS database has been broadly used for epidemiological and public health research and policymaking. The details of this database are described elsewhere.¹⁴ Our study population comprised 361 713 participants aged ≥ 50 years who had registered for national health examinations from 2009 to 2010 and were followed up from 2011 to 2013 (*Figure 1*). Our study excluded subjects with fractures diagnosed prior to the index date ($n = 20\,391$) and those who had died prior to the index date ($n = 1113$). Participants with missing values for BMI ($n = 157$), age < 50 years ($n = 39\,682$), and covariates ($n = 10\,357$) were also excluded. In total, 290 013 Korean adults (men, $n = 158\,426$; women, $n = 131\,587$) were included in the final study. This study was approved by the Institutional Review Board of the Seoul National University Hospital (institutional review board approval number: 1703-039-836). The requirement for informed consent was waived as the NHIS-HEALS was constructed after anonymization according to strict confidentiality guidelines before distribution.

Exposure measurements: predicted body composition

In our study, the predicted lean BMI (pLBMI), the predicted appendicular skeletal muscle mass index (pASMI), and the predicted body fat mass index (pBFMI) were assessed and calculated using anthropometric prediction equations that were developed and validated in a study on a representative cohort of 17 608 Korean population from the Korean National Health and Nutrition Examination Survey 2008–2011.¹³ This previous study performed multivariable linear regressions to develop prediction equations for the following components that were assessed by DXA as dependent variables: lean body mass (LBM), appendicular skeletal muscle mass (ASM), and body fat mass (BFM); furthermore, the predictor variables used were age, anthropometric values (i.e. height, body weight, and waist circumference), serum creatinine level, and health behaviour factors (i.e. physical activity, smoking, and alcohol intake). A Bland–Altman plot was also generated during the previous

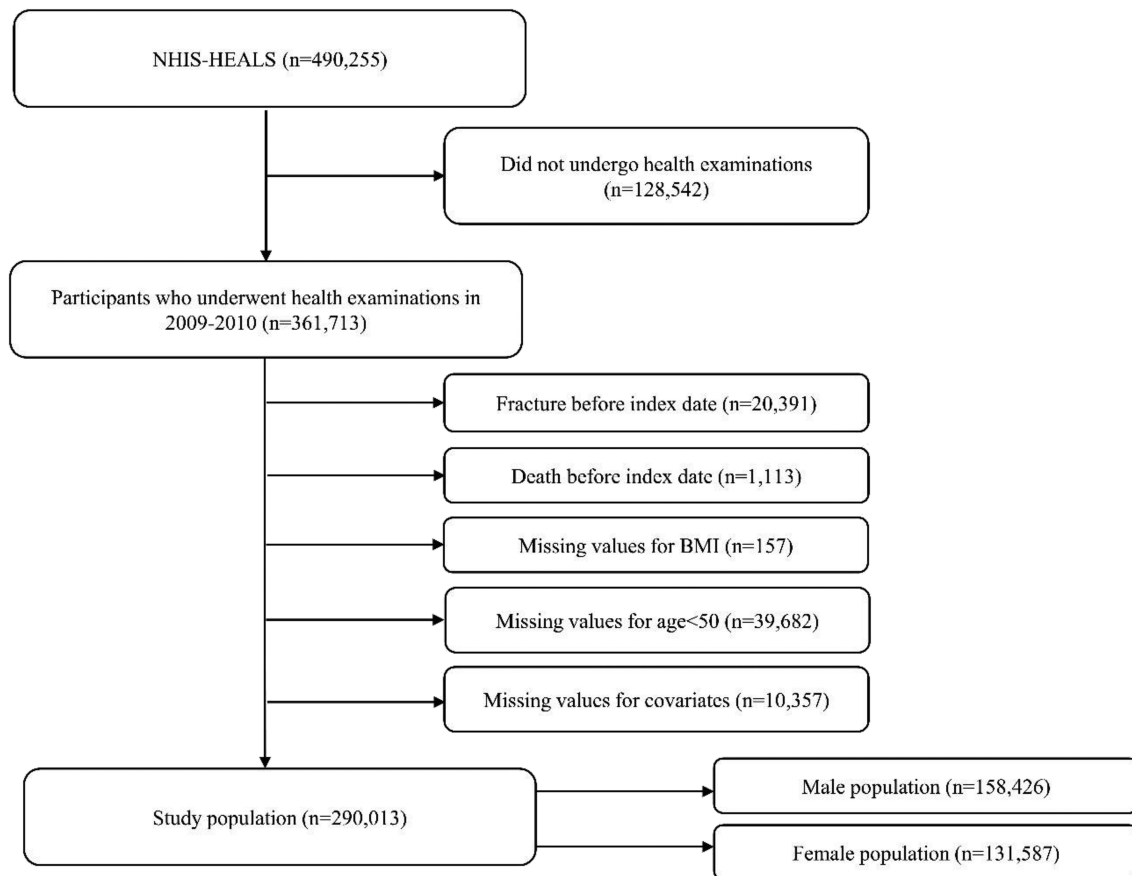


Figure 1 Flow diagram of selection of study population. BMI, body mass index; NHIS-HEALS, National Health Insurance Service-Health Screening.

study, and the intraclass correlation coefficient for validation was calculated. All these prediction equations have been found to have high predictive power, low bias, and moderate agreement when practised in large-scale studies. Moreover, each part of masses was also adjusted for height; the LBM, ASM, and BFM were represented by an index and calculated by dividing the weight (kg) by height squared (m^2). By applying the previously mentioned prediction equations, we calculated the body composition including the pLBMI, pASMI, and pBFMI.

Sarcopenia, a geriatric condition accompanied by a decline in muscle mass, is generally defined by an ASMI < 2 SDs below the mean values of ASMI in young reference groups. Sarcopenia is also defined by authorized working groups such as the European Working Group on Sarcopenia in Older Persons and the Asian Working Group for Sarcopenia as the lowest quintile of the study population.^{15,16} Several working groups have suggested various cut-off values for muscle mass reduction, but each has uncertain levels and different clinical implications. In addition, muscle strength or physical performance as well as muscle mass for sarcopenia varies depending on race. Despite the clinical significance of body composition, universally standardized criteria of muscle and

fat masses are not available to date. For this reason, we have reported our results according to body composition quintile categories, using the first (lowest) quintile group as the reference group.

Determining outcomes: risk of osteoporotic fracture

The primary outcome was the incidence of osteoporotic fractures, defined as ≥ 1 day of hospitalization or ≥ 2 days of outpatient visits within 1 year that were assigned fracture-related diagnostic codes on claim records. The International Classification of Diseases, Tenth Revision codes identifying osteoporosis-related fractures are identified from the publication in the form of the fact sheet reported by the Korean Society of Bone and Mineral Research³: S22.0 (fracture of the thoracic spine), S22.1 (multiple fractures of the thoracic spine), S32.0 (fracture of the lumbar spine), M48.4 (fatigue fracture of a vertebra), and M48.5 (collapsed vertebra) for spine fracture; S72.0 (fracture of the femur neck), S72.1 (trochanteric fracture), S52.5 (fracture of the distal radius), S52.6 (combined fracture of the distal ulnar and

radius), S42.2 (fracture of the proximal humerus), and S42.3 (fractured shaft of the humerus) for non-spine fracture comprising the hip, radius, ulna, and humerus. Based on this classification, previous studies have reported fracture outcomes using the National Health Insurance Database.^{17,18} All participants who had registered between 2009 and 2010 were followed up from the index date (1 January 2011) until the date of osteoporotic fracture or death (31 December 2013), whichever occurred first.

Statistical analysis

Participants' baseline characteristics according to sex were determined using one-way analysis of variance for continuous variables and χ^2 test for categorical variables. We performed multivariate Cox proportional hazards regression analysis to estimate the adjusted hazard ratios (aHRs) and 95% confidence intervals (CIs) for osteoporotic fracture risk in relation to the effects of the pLBMI, pASMI, and pBFMI, after adjustment for sociodemographic data, health behaviour, and health-related laboratory results in this analysis. We included possible covariates in our analysis as follows: age, sex, household income, smoking status (never, past,

and current smoker), alcohol intake (none, moderate, and heavy), physical activity (low, moderate, and vigorous), systolic blood pressure, serum total cholesterol, fasting blood glucose levels, BMI, and the Charlson Comorbidity Index. Additionally, the association between body composition and categorical osteoporotic fracture sites (total, spine, and non-spine) was evaluated in subgroup analyses. All statistical analyses were conducted using SAS software (Version 9.4, SAS Institute Inc., Cary, NC, USA) and STATA software (Version 16.0, StataCorp LP, College Station, TX, USA). A *P* value of <0.05 was considered statistically significant.

Results

Table 1 demonstrates the baseline characteristics of 291 473 enrolled subjects according to sex (men, *n* = 159 358; women, *n* = 132 115). The mean age (standard deviation) in men was 60.2 (8.3) years and in women was 60.7 (8.4) years. The number of total osteoporotic fracture events was 2350 (1.5%) in men and 6175 (4.7%) in women. There were distinct differences in values in relation to the general characteristics between the sexes. Women were more likely to have lower

Table 1 Baseline characteristics of the study population

| | Men | Women | <i>P</i> value |
|--|----------------|----------------|----------------|
| Number of people, <i>N</i> (%) | 158 426 (54.6) | 131 587 (45.4) | |
| Fracture events, <i>N</i> (%) | 2350 (1.5) | 6175 (4.7) | <0.001 |
| Age (years), mean (SD) | 60.2 (8.3) | 60.7 (8.4) | <0.001 |
| Household income (quartile), <i>N</i> (%) | | | <0.001 |
| 1st (highest) | 61 087 (38.6) | 39 881 (30.3) | |
| 2nd | 47 272 (29.6) | 38 924 (29.6) | |
| 3rd | 30 688 (19.4) | 29 765 (22.6) | |
| 4th (lowest) | 19 379 (12.2) | 23 017 (17.5) | |
| Smoking, <i>N</i> (%) | | | <0.001 |
| Never smoker | 58 838 (37.1) | 128 553 (97.7) | |
| Past smoker | 53 126 (33.5) | 926 (0.7) | |
| Current smoker | 46 462 (29.3) | 2108 (1.6) | |
| Physical activity (MET-min/week), <i>N</i> (%) | | | <0.001 |
| Low (<600 METs) | 84 359 (53.3) | 82 455 (62.7) | |
| Moderate (600–2999 METs) | 74 067 (46.8) | 49 132 (37.3) | |
| Alcohol consumption (times per week), <i>N</i> (%) | | | <0.001 |
| None | 63 156 (39.9) | 115 221 (87.6) | |
| Moderate | 60 987 (38.5) | 12 344 (11.5) | |
| Heavy | 34 283 (21.6) | 4022 (3.06) | |
| Systolic blood pressure (mmHg), mean (SD) | 126.7 (14.8) | 124.4 (15.7) | <0.001 |
| Fasting serum glucose (mg/dL), mean (SD) | 103.8 (27.4) | 98.5 (22.4) | <0.001 |
| Total cholesterol (mg/dL), mean (SD) | 195.0 (36.7) | 206.6 (38.2) | <0.001 |
| Body mass index (kg/m ²), mean (SD) | 24.1 (2.8) | 24.0 (3.1) | 0.020 |
| Predicted body composition index (kg/m ²), mean (SD) | | | |
| pLBMI | 18.2 (1.5) | 15.7 (1.3) | <0.001 |
| pASMI | 7.9 (0.7) | 6.3 (0.6) | <0.001 |
| pBFMI | 5.6 (1.3) | 8.2 (1.8) | <0.001 |
| Charlson Comorbidity Index, <i>N</i> (%) | | | <0.001 |
| 0 | 34 768 (22.0) | 19 395 (14.7) | |
| 1 | 44 338 (28.0) | 33 579 (25.5) | |
| ≥2 | 79 320 (50.0) | 78 613 (59.8) | |

METs, metabolic equivalents; *N*, number of people; pASMI, predicted appendicular skeletal muscle mass index; pBFMI, predicted body fat mass index; pLBMI, predicted lean body mass index; SD, standard deviation.

P value calculated by χ^2 test for categorical variables and one-way analysis of variance for continuous variables.

levels of physical activity, less alcohol consumption, and lower smoking rates than men. Women also tended to have a lower pLBMI, lower pASMI, and higher pBFMI than men.

Figure 2 shows the association between predicted body composition and total fracture risk in men and

women. A multivariable-adjusted Cox model showed that an increased pLBMI or pASMI was significantly associated with a decreased risk of total fractures in men and women. However, in terms of the pBFMI, no significant association was found concerning total fracture

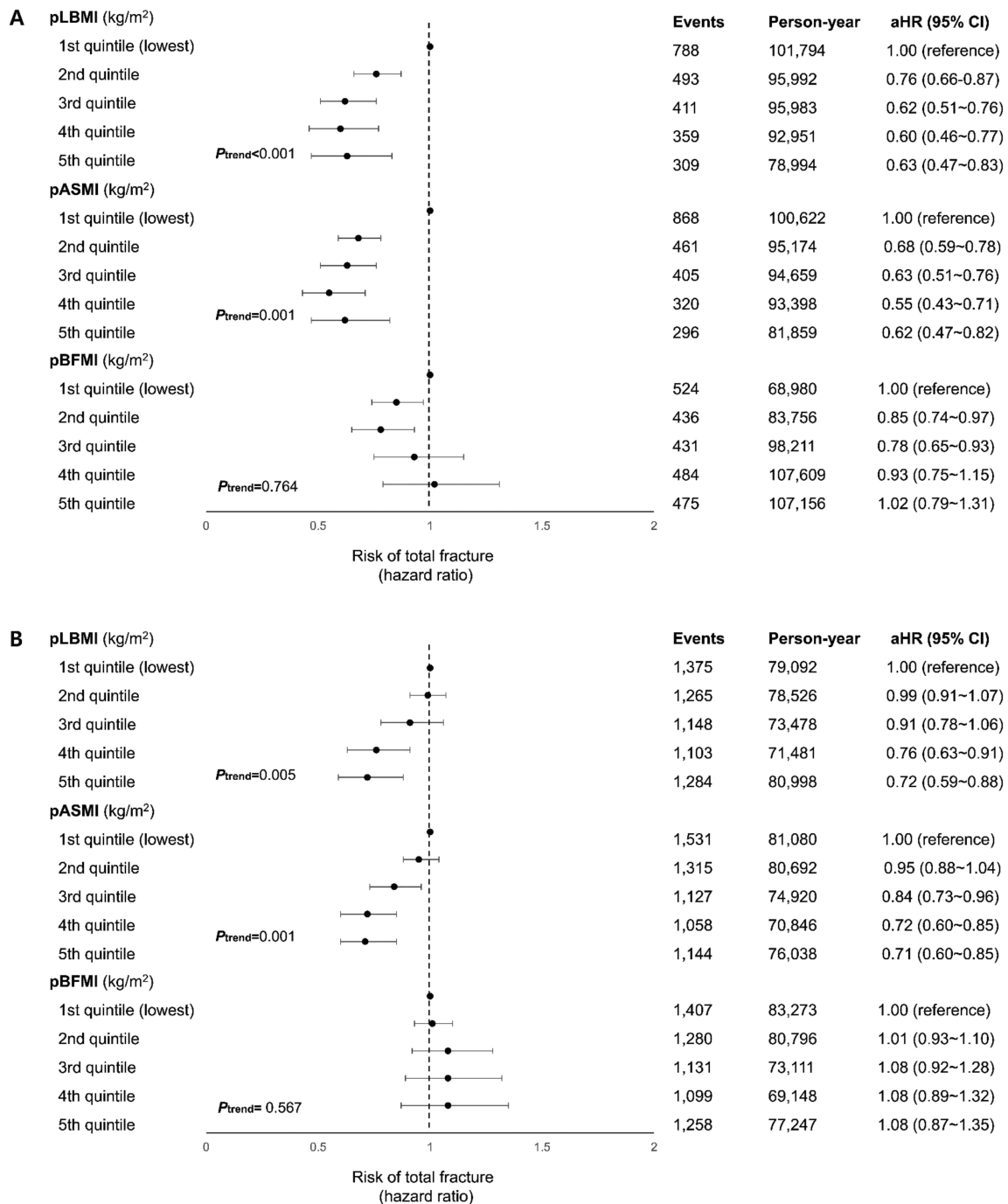


Figure 2 Association of the predicted lean body mass index (pLBMI), predicted appendicular skeletal muscle index (pASMI), and predicted body fat mass index (pBFMI) with total fracture in (A) men and (B) women. Hazard ratios are represented by black circles, where black lines correspond to 95% confidence interval (CI) bounds from forest plots. Hazard ratios (95% CI) were calculated by Cox proportional hazards regression analysis after adjusting for age, income, physical activity, smoking, alcohol consumption, systolic blood pressure, fasting serum glucose, total cholesterol, Charlson Comorbidity Index, and body mass index. aHR, adjusted hazard ratio.

risk between men and women (Supporting Information, Table S1).

Figure 3 demonstrates the association between predicted body composition and spine fracture risk in men and women. In men, a high pLBMI or pASMI was associated with a

decreased risk of a spine fracture. In particular, the aHR (95% CI) for spine fracture in the fourth pASMI quintile in men was 0.39 (0.27–0.56) compared with the first pASMI quintile, which indicated that the aHR magnitude identified was more precise than that of the pLBMI. Moreover, the as-

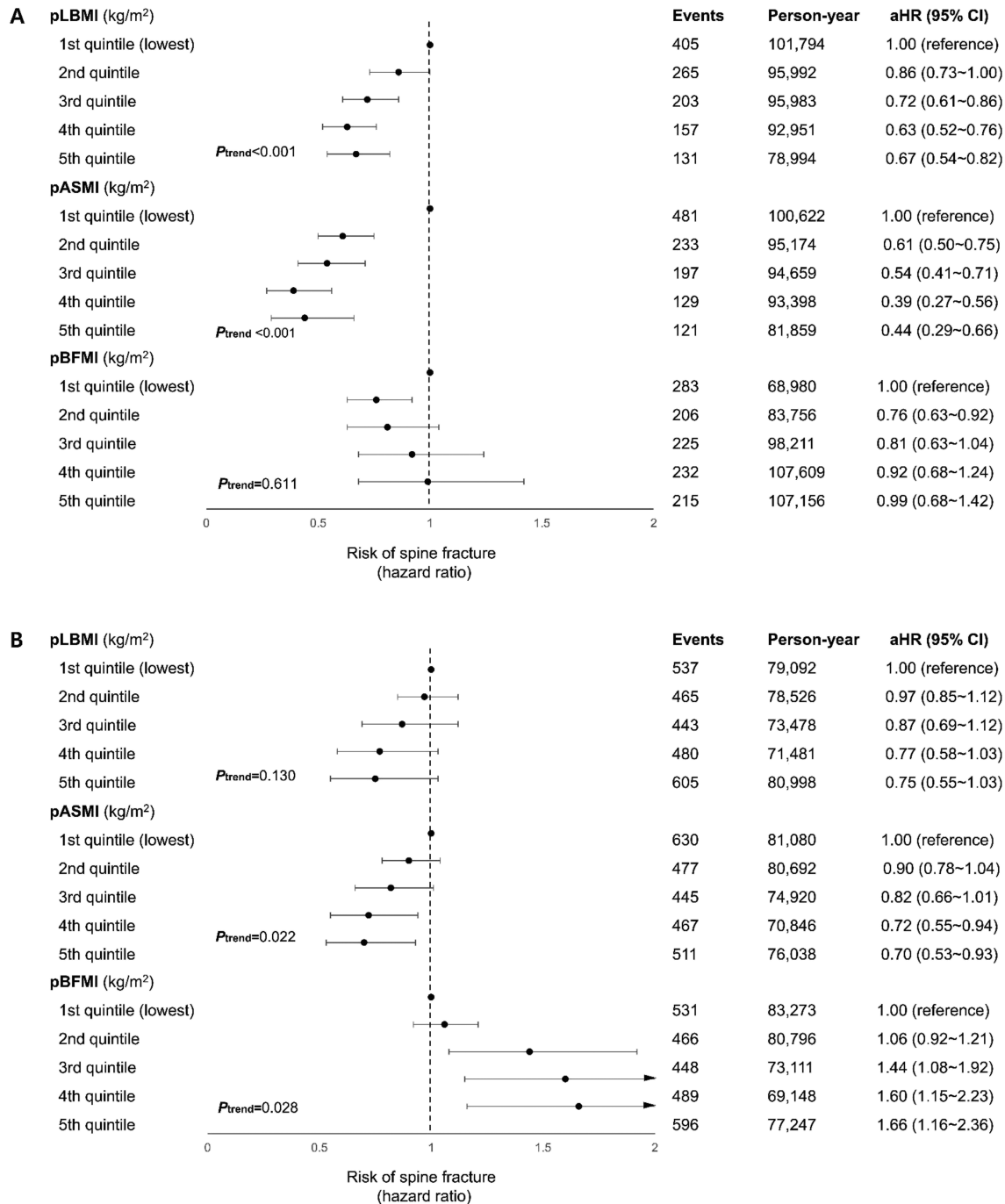


Figure 3 Association of the predicted lean body mass index (pLBMI), predicted appendicular skeletal muscle index (pASMI), and predicted body fat mass index (pBFMI) with spine fracture in (A) men and (B) women. Hazard ratios are represented by black circles, where black lines correspond to 95% confidence interval (CI) bounds from forest plots. Hazard ratios (95% CI) were calculated by Cox proportional hazards regression analysis after adjusting for age, income, physical activity, smoking, alcohol consumption, systolic blood pressure, fasting serum glucose, total cholesterol, Charlson Comorbidity Index, and body mass index. aHR, adjusted hazard ratio.

sociation between the pBFMI and spine fracture risk differed according to sex. The pBFMI was not associated with a risk of spine fracture among men, whereas there was a significant positive relationship between the pBFMI and spine fracture risk in women (Table S2).

Figure 4 shows the association between predicted body composition and non-spine fracture risk involving the hip, the humerus, and the radius in men and women. A high pLBMI was associated with a decreased non-spine fracture risk among men and women, whereas a high pASMI was as-

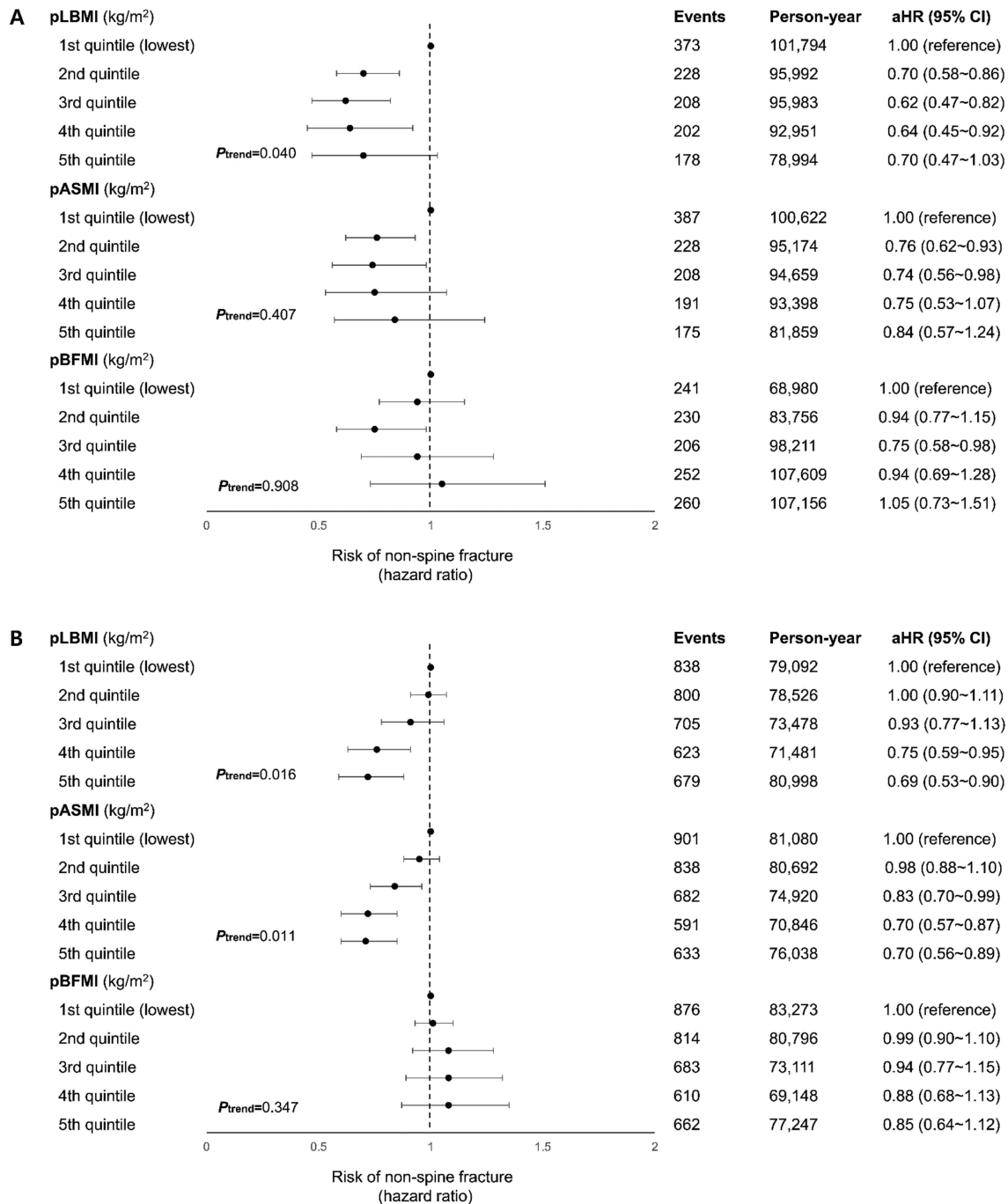


Figure 4 Association of the predicted lean body mass index (pLBMI), predicted appendicular skeletal muscle index (pASMI), and predicted body fat mass index (pBFMI) with non-spine fracture in (A) men and (B) women. Hazard ratios are represented by black circles, where black lines correspond to 95% confidence interval (CI) bounds from forest plots. Hazard ratios (95% CI) were calculated by Cox proportional hazards regression analysis after adjusting for age, income, physical activity, smoking, alcohol consumption, systolic blood pressure, fasting serum glucose, total cholesterol, Charlson Comorbidity Index, and body mass index. aHR, adjusted hazard ratio.

sociated with a reduced risk of non-spine fracture in women but not in men. In addition, there was no statistically significant association between the pBFMI and non-spine fracture in both sexes (Table S3).

Figure 5 presents forest plots of aHRs and 95% CIs per changes in the inter-quintile range (IQR) for predicted body composition and fracture risks in men and women. For each IQR, pLBMI and pASMI were associated with a reduced risk

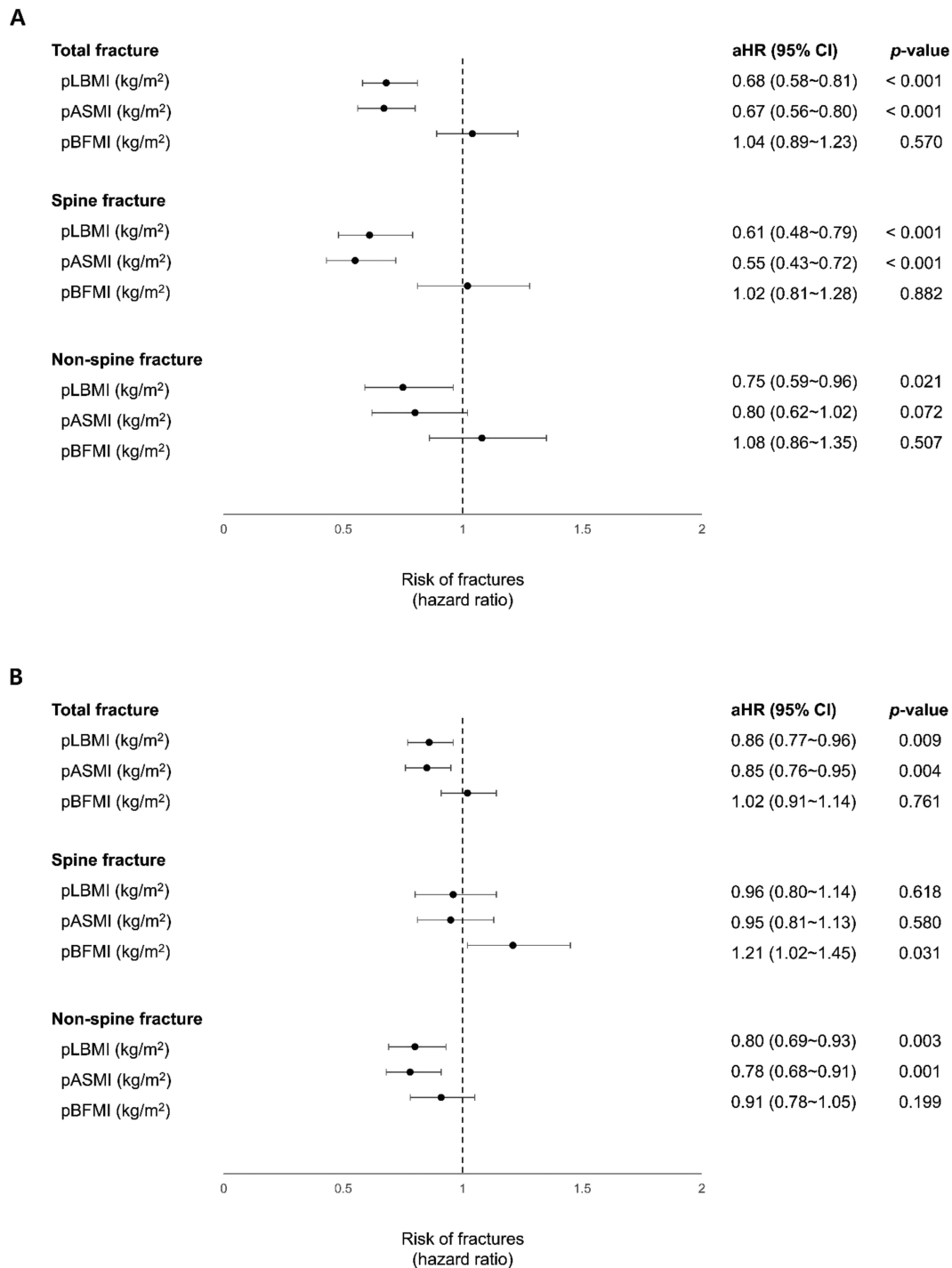


Figure 5 Association of the predicted lean body mass index (pLBMI), predicted appendicular skeletal muscle index (pASMI), and predicted body fat mass index (pBFMI) presented by changes per inter-quintile range with the total, spine, and non-spine fractures in (A) men and (B) women. Hazard ratios are represented by black circles, where black lines correspond to 95% confidence interval (CI) bounds from forest plots. Hazard ratios (95% CI) were calculated by Cox proportional hazards regression analysis after adjusting for age, income, physical activity, smoking, alcohol consumption, systolic blood pressure, fasting serum glucose, total cholesterol, Charlson Comorbidity Index, and body mass index. aHR, adjusted hazard ratio.

of total fracture and non-spine fracture, but pBFMI was not associated with a decreased risk of total fracture and non-spine fracture in men and women. Furthermore, for each IQR, the pLBMI and pASMI reduced the risk of spinal fracture in men, and pBFMI increased risk of spinal fracture in women. Generally, the aHR of pASMI to fracture risk tends to be lower than that of the pLBMI to fracture risk (Table S4).

Discussion

In this general population-based, longitudinal cohort study, we investigated the association between body composition and osteoporotic fracture risks in a Korean adult population using anthropometric prediction equations. We found that an increased pLBMI or pASMI was associated with a decreased risk of total osteoporotic fractures. However, the pBFMI showed no significant statistical association after adjusting for various covariates, including BMI, to compensate for weight-bearing effects in men and women. Our findings indicated that muscle mass, rather than fat mass, was more important in terms of bone protection and bone fracture prevention. To our knowledge, this study is the first cohort study to examine the association of body composition and osteoporotic fracture risks using a large sample size and validated anthropometric prediction equations in an Asian population.

Body composition is composed of three compartments, namely, lean mass, fat mass, and bone mass. LBM refers to the total body mass minus the fat mass and thus comprises the combined weight of the muscles, bones, organs, skin, and blood. ASM accounts for ~75% of the total skeletal muscle mass and has received increased attention because it determines the ability to perform daily physical activities related to sarcopenia, which is defined as a loss of skeletal muscle (estimated using ASM).¹⁹ To evaluate body composition independently, it is necessary to differentiate between BFM and LBM.^{20,21} Moreover, as LBM includes both the lean mass of the entire trunk and the skeletal mass of the limbs, we calculated the pLBMI and the pASMI separately to distinguish ASM from LBM to emphasize the effect of skeletal muscle mass on fractures.

Muscle mass and osteoporotic fracture

Previous reports have demonstrated the beneficial role of muscle mass in maintaining bone mass.⁷ Muscle mass increases bone density through both mechanical loading and molecular signalling.²² Furthermore, muscle affects the skeletal metabolism by regulating levels of hormones and bone anabolic factors.²² A low LBM may have negative effects on BMD and contribute to declining muscle strength, leading to an increased risk of falls.²³ A meta-analysis of the associa-

tion between lean mass, fat mass, and BMD reported that lean mass is a more important factor than fat mass in BMD in both sexes of all ages and ethnicity.²⁴ In a recent systematic review and meta-analysis, sarcopenia was found to be positively associated with fractures.²⁵ Similar to those of previous studies, our findings also showed that a high pLBMI or pASMI was significantly associated with a decreased total fracture risk after adjusting for confounders, specifically including BMI, in both sexes.

Our study showed further evidence that this relationship varied depending on sex and skeletal anatomical site. Based on sex-specific or site-specific differences, the protective effect of muscle mass was more prominent in men than in women. In addition, the protective effect of the pASMI, rather than the pLBMI, tended to be stronger for fractures in both sexes. With regard to sex differences, previous studies have suggested that, as men have a smaller proportion of fat mass and a more rapid loss of muscle depending on their age as well as a relatively larger degree of decline in the testosterone and IGF-1 levels compared with those in women, the effect of muscle on bone appears stronger and more favourable in men than in women.^{26,27}

Our results showed that the pLBMI reduced the risk of spine fracture in men but not in women. Kim *et al.* also reported a sex-dependent relationship between body composition and fracture incidence among Korean adults in a prospective cohort study, suggesting low lean mass as a risk factor of fragility fracture in men but not in women.²³ Site-specific differences found between ASM and femur BMD may be further explained through mechanical loading on bone where the femur, rather than the spine, is the main region where mechanical loading is exerted and where weight-bearing occurs.²⁸ However, the biological mechanisms that underlie these sex-specific or site-specific differences remain unclear and need to be elucidated through future studies. In addition, fractures are affected by both skeletal components such as bone turnover, strength, and BMD and non-skeletal components such as functional impairment, physical performance, disability, and falls.²⁹ Further large-scale studies are necessary to clarify the relationship between muscle mass and the various risk factors of fractures such as BMD and falls.

Fat mass and osteoporotic fracture

Obesity is commonly considered to have a protective effect on bone metabolism; however, a recent study reported that obesity had no benefits in relation to fractures in contrast to its positive effect on weight-bearing.³⁰ The relationship between obesity and bone health may differ according to the definition of obesity. If the definition is based on BMI, obesity appears to protect bony structures, whereas if it is based on the proportion of fat mass or adipose tissue, it

may be a risk factor for bone health.³¹ Our study showed that the pBFMI was not significantly associated with total fracture risks in both sexes. Adjustment for mechanical loading of body weight as a potential confounding factor is required to determine the relationship between body composition and fracture risk. Therefore, the aHRs of fracture risks in our data were all corrected with BMI as the main covariate to compensate for this weight-bearing effect; as a result, no association between fat mass and fractures was found. Complex pathophysiological interactions are observed between fat and bone metabolism. Fat accumulation promotes adipocyte differentiation by promoting hormone secretion (adiponectin, leptin, and sex hormones) and producing pro-inflammatory cytokines (interleukin-6, tumour necrosis factor- α , and C-reactive protein), which modulate osteoblast–osteoclast interaction. In addition, fat distribution (visceral or subcutaneous fat) influences bone formation. At present, the net beneficial or harmful effect of fat mass on bone remains controversial.³² Furthermore, our analysis indicated that the pBFMI influenced the increase in spine fracture risk only in women. A possible mechanism explaining the adverse effect in this association between pBFMI and spine fracture in women may be metabolically active abdominal fat tissue. Furthermore, the inflammatory signalling pathways appear to be higher with excessive abdominal fat, which stimulates osteoclastogenesis and bone loss.³³ Based on sex or site differences, women have been reported to have higher rates of metabolic syndrome (MS) and more abdominal fat than men, as they undergo physiological changes during the postmenopausal stage.^{34,35} The results of a longitudinal study involving 417 men and 671 women indicated that, after adjusting for BMI, MS was related to lower BMD and may be a risk factor for fractures.³⁶ Regarding the distribution of fat mass, a prospective cohort study that involved 54 934 participants reported that central obesity increased spine fracture risks, suggesting that fat distribution can predict spine fracture risks; thus, spine fracture risk may be reduced by decreasing abdominal obesity and maintaining muscle mass in older women.³⁷ Similar to our findings, one study suggested that high fat mass, abdominal obesity, and MS were associated with vertebral fractures in Korean women aged 60–79 years.³¹

Our findings did not support the obesity paradox. This controversial hypothesis does not differentiate between the lean and adipose tissue compartments in terms of prognosis for morbidity and mortality due to the methodological limitations attributed to using BMI. Although an alternative approach that includes DXA, bioelectrical impedance analysis, computed tomography scanning, and magnetic resonance imaging has been considered, limitations exist because of high price, time constraints, and the need for specialization; moreover, these procedures are performed only in limited research and medical facilities and are not feasible for large-scale screening.¹² However, anthropometric measures are easily applied, less expensive, non-invasive, and more

available in a practical setting; hence, they are widely used as measures in large health surveys and cohort studies.¹⁹ For this reason, we applied prediction equations using anthropometric measures in this study. Further analysis of assessment tools for body composition is required to elucidate the obesity paradox phenomenon when predicting bone health outcomes.

Strengths and limitations

Our study has some potential limitations; thus, the results must be carefully interpreted with attention to the following limitations. First, the predicted body composition is an imperfect measurement; this may have resulted in measurement errors. The prediction equations in our study showed a moderate level of agreement with the DXA measurement, indicating that these equations may be restricted when applied in small populations or individuals. However, because the results of a previous large validation study based on Korean National Health and Nutrition Examination Survey showed high predictive values, including low bias, high ICC, high adjusted R^2 , and low SEE, these prediction equations can be fully available in large-scale research and epidemiological studies. Second, there are no imaging records such as X-rays in the NHIS dataset to support the operational definition of osteoporotic fracture. In addition, the NHIS database has no information such as BMD, steroid treatment, hormone replacement therapy, and previous history of fracture, which are considered the determinants of osteoporotic fractures risks. To overcome these limitations, we used Charlson Comorbidity Index to compensate for the effect of potential covariates. Further trials considering fracture risk factors as confounders are required. Third, ethnicity-specific differences in body composition are another potential limitation. Asians have a higher body fat percentage, prominent abdominal obesity, and a higher intramyocellular lipid content compared with Caucasians.³⁸ In addition, Asians have less lean mass at a similar body size than Europeans, which persists after adjustment for confounders such as age, height, and lifestyle.³⁹ In the present study, all subjects were recruited from a Korean population, and the prediction equations were also derived and validated from a Korean population; thus, they can be applied to the Asian population. Therefore, the application of our results to all ethnic groups might be limited. Fourth, the NHIS database was collected from 2002 and followed up through to 2013. Our study could not include the latest and integrated representative cohort of the NHIS because the database has not been updated. However, if updated data are available, a longer period of follow-up research will be possible in the future.

Despite these limitations, the application of anthropometric prediction equations enabled the estimation of the amount of muscle and fat mass in a large population in a

practical setting. Based on these equations, we considered LBM, ASM, and BFM simultaneously, which reflects what is performed in real practice and also allowed us to understand the influence of muscle and fat mass in predicting fracture risk. Moreover, we designated the primary outcome as fractures, which is the most robust outcome variable to reflect bone health, rather than BMD. Despite low BMD being an important risk factor influencing fractures, it is one of the surrogate markers for predicting clinical outcomes, and fracture risk also includes non-skeletal risk factors such as falls. Therefore, more factors related to bone properties were considered. Consequently, the findings of this study reveal a strong relationship between body composition and osteoporotic fractures in a Korean adult population.

Conclusions

Our study found that increased muscle mass reduced osteoporotic fracture risks. However, based on anthropometric prediction equations among Korean adults aged ≥ 50 years, fat mass was not statistically related to this outcome. Our findings indicated that muscle mass, rather than fat mass, was a more important determinant for fracture risk; therefore, increasing muscle mass is pivotal to preventing osteoporotic fractures. From a public health perspective, anthropometric methods to estimate muscle or fat mass may be a clinically useful measurement in the development of body composition and fracture risk prediction models in the future, providing additional insights into how muscle or fat mass independently affect bone health and to help clarify controversial issues in terms of the obesity paradox in relation to bone mass. Public health strategies to change health promotion behaviour for healthy body composition may be helpful for maintaining bone health in adult populations.

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Online supplementary material

Additional supporting information may be found online in the Supporting Information section at the end of the article.

Table S1. Hazard ratios (95% CI) for total fracture according to the predicted LBMI, ASMI, and BFMI among adults aged older than 50 years.

Table S2. Hazard ratios (95% CI) for spine fracture according to the predicted LBMI, ASMI, and BFMI among adults aged older than 50 years.

Table S3. Hazard ratios (95% CI) for non-spine fracture according to the predicted LBMI, ASMI, and BFMI among adults aged older than 50 years.

Table S4. Hazard ratios (95% CI) presented by change per inter-quintile range (IQR) for total, spine, and non-spine fractures according to the predicted LBMI, ASMI, and BFMI among adults aged older than 50 years.

Conflict of interest

None declared.

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