Several epidemiological studies have shown that high body weights or high body mass indices (BMI) are related to a high bone mass, and that decreases in body...
Any patient with vertebral fractures due to known accidental traumas were also excluded.

**Data collection**

Body weight (kg), BMI (kg/cm²), percent body fat (%), and abdominal circumference (cm) were measured and serum glucose (mg/dL) to evaluate adiposity, triglyceride (mg/dL), HDL cholesterol (mg/dL), and low density lipoprotein (LDL) cholesterol (mg/dL) were measured in fasting blood samples. Systolic and diastolic blood pressures were measured by nurses. The definition of metabolic syndrome was followed by the National Cholesterol Education Program’s Adult Treatment Panel III (NCEP III) guidelines.17

Osteoporosis parameters included BMD (g/cm²) in the hip and spine, vertebral fractures, urine deoxypyridinoline (DPD), and serum total osteocalcin (OC). Lateral radiographs of the thoracic and lumbar spine demonstrating the presence of vertebral fractures were interpreted by radiographic morphometry using Genant’s semi-quantitative method.18 BMD determined at the lumbar spine (L2-L4) was assessed using dual energy X-ray absorptiometry (DEXA). Lunar (Madison, WI, USA) scanners were used in this study. Nutritional assessment was performed by dietitians using a 24 hr diet recall method.19 From this, we calculated the status of energy expenditure, total calorie intake, calcium intake, and fat intake.

This study was conducted after approval of all research procedures by the hospital institutional review board (IRB). Written informed consent was obtained from all subjects.

**Statistical analysis**

Statistical analyses were performed using SAS software for Windows (v.9.1, Cary, NC, USA). Categorical variables were summarized using frequencies and percentages, while continuous variables were summarized using sample size, mean, median, standard deviation, and minimum and maximum values. Significance was declared at a two-sided 0.05 level, unless otherwise specified. To adjust for age, body weight, percentage body fat, smoking status, alcohol consumption, total energy expenditure, total calcium intake, and total fat and cholesterol intake, we used a general linear model for continuous dependent variables (BMD, metabolic syndrome, osteoporosis, bone health).
bone marker, lipid profile, etc.) and a logistic regression model for categorical dependent variables (risk of osteoporotic fracture and metabolic syndrome). An association between the independent variables group and the risk of osteoporotic fracture and metabolic syndrome was calculated using odds ratios and 95% confidence intervals (CI).

**RESULTS**

The major characteristics of the 907 subjects are shown in Table 1. The average age of the recruited patients was 65.18 ± 5.42 years. Among the 907 subjects, 302 (33%) individuals were overweight and 341 (38%) were obese. The prevalence of metabolic syndrome was 34%, which is close to the value of 32.6% reported for the Korean population (2005, the Third Korea National Health and Nutrition Examination Survey, KNHANES III ). The average lumbar BMD (L BMD) was 0.84 ± 0.26 g/cm², while the average femoral BMD (neck, trochanter, ward) was 0.67 ± 0.12, 0.54 ± 0.09, and 0.45 ± 0.11 g/cm², respectively. Among the 907 subjects, 44 (5%) individuals had a normal BMD, 350 (38%) were osteopenia, and 513 (56%) were osteoporosis. The prevalence of osteoporotic lumbar fractures was 21% in this study. Because no official statistics for osteoporotic vertebral fractures are available for Korea, we were not able to determine whether this value is representative of the general Korean population.

A simple correlation analysis revealed that both body weight (r = 0.2947, p < 0.001) and percentage body fat (r = 0.1935, p < 0.0001) were significantly and positively related to lumbar BMD (data not shown). However, waist circumference was negatively related to the lumbar and all femur site BMD after adjusting for age, smoking status, alcohol consumption, total calcium intake, total energy intake, and body weight (Table 2). Percentage body fat was also negatively correlated to trochanter BMD but not to other sites.

The serum glucose level was positively correlated to lumbar BMD (p = 0.016), femoral neck BMD (p = 0.0335), and femoral trochanter BMD (p = 0.0082). Serum high density lipoprotein cholesterol (HDLC) was only related to femoral trochanter BMD (p = 0.0366). Serum TG and systolic blood pressure (BP) were not related to BMD at any site.

Table 3 demonstrates differences in independent variables between the fracture and non-fracture groups. The average age of subjects in the fracture group was higher than that of the non-fracture group (odds ratio 1.077, 95% CI 1.042-1.114). The average body weights and BMIs of the two groups were not significantly different. However, the percentage body fat and waist circumference were much higher in the fracture group than the non-fracture group (odds ratio 1.064, 95% CI 1.003-1.129, odds ratio 1.043, 95% CI 1.011-1.077, respectively Fig. 1).

| Table 1. Characteristics of the Subjects |
|-----------------------------------------|
| Variables                  | Subgroup       | Mean ± SD | n  | %  |
| Age (yr)                   |                | 65.18 ± 5.42 |   |    |
| Body fat (%)               |                | 34.67 ± 2.95 |   |    |
| BMI (kg/cm²)               |                | 24.11 ± 2.68 |   |    |
| BMI*                       | Normal         | 302        | 33%|
|                           | Overweight     | 264        | 29%|
|                           | Obesity        | 341        | 38%|
| Waist (cm)                 |                | 88.89 ± 7.59 |   |    |
| Systolic BP (mmHg)         |                | 131.4 ± 16.19 |   |    |
| TG (mg/dL)                 |                | 126.89 ± 71.83 |   |    |
| HDL (mg/dL)                |                | 54.72 ± 13.51 |   |    |
| Glucose (mg/dL)            |                | 87.26 ± 18.81 |   |    |
| Metabolic Syndrome         | Yes            | 317        | 34%|
|                           | No             | 590        | 66%|
| BMD¹                      | Normal         | 44         | 5% |
|                           | Osteopenia     | 350        | 38%|
|                           | Osteoporosis   | 513        | 56%|
| Vertebral Fracture         | Yes            | 189        | 21%|
|                           | No             | 711        | 79%|

BMI, body mass index; BMD, bone mineral density; HDL, high density lipoprotein; TG, triglyceride; BP, blood pressure.

*Normal, BMI < 23; overweight, 23 ≤ BMI < 25; obese, BMI ≥ 25.
  *Normal, T score > -1.0; osteopenia, -1.0 ≤ T score < -2.5; osteoporosis, T score ≤ -2.5.
Both obesity and osteoporosis are common diseases that affect millions of people. In recent decades, the association between obesity and osteoporosis has been actively investigated both from an epidemiological standpoint and from a basic research standpoint, and common pathogenic links have been proposed.\textsuperscript{1-3,6,18} Although it is generally accepted that obesity has a protective effect on bone tissue, some studies have revealed the opposite: that obesity is not beneficial or has a negative effect on osteoporosis.\textsuperscript{21} The relationship between obesity and osteoporosis varies depending on how obesity is defined. If obesity is defined on the basis of BMI or body weight, obesity appears to be a protective factor against bone mineral loss or vertebral fractures. However, if obesity is based on the percentage body fat, obesity

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**Table 2. Metabolic Variables Relating to BMD**

| Variable      | Lumbar F value | p value | Neck F value | p value | Trochanter F value | p value | Ward F value | p value |
|---------------|---------------|---------|--------------|---------|-------------------|---------|--------------|---------|
| Wt (kg)       | 5.53          | < 0.001 | 6.21         | < 0.001 | 7.51              | < 0.001 | 4.91         | < 0.001 |
| Body fat (%)  | -0.93         | 0.096   | -0.78        | 0.432   | -2.31             | 0.021   | -1.36        | 0.173   |
| Waist (cm)    | -2.09         | 0.037   | -5.07        | < 0.001 | -4.58             | < 0.001 | -5.01        | < 0.001 |
| Glucose (mg/dL)| 2.36        | 0.016   | 2.13         | 0.033   | 2.65              | 0.008   | 1.02         | 0.309   |
| HDLC (mg/dL)  | 1.57          | 0.107   | 1.25         | 0.212   | 2.09              | 0.036   | 0.73         | 0.465   |
| TG (mg/dL)    | 1.98          | 0.060   | -0.2         | 0.840   | 1.03              | 0.302   | -0.2         | 0.843   |
| Systolic BP   | 0.6           | 0.592   | -0.77        | 0.438   | -1.45             | 0.148   | -1.26        | 0.207   |

BMD, bone mineral density; HDLC, high density lipoprotein; TG, triglyceride; BP, blood pressure. All variables are adjusted for age, smoking status, alcohol consumption, total calcium intake, total energy expenditure, and total calorie intake and variable of Wt (kg) is additionally adjusted by body fat (%), whereas variable of body fat (%) and waist (cm) are adjusted by Wt (kg), respectively.

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**Table 3. Metabolic Variables Affecting the Incidence of Osteoporotic Fractures**

| Variables | Fracture | Non-fracture | OR (95% CI) | p value |
|-----------|----------|--------------|-------------|---------|
| n (%)     | 189 (21%)| 711 (79%)    |             |         |
| Wt (kg)   | 57.47 ± 7.73 | 57.39 ± 7.04 | 0.182       |         |
| BMI (kg/cm\textsuperscript{2}) | 24.58 ± 2.95 | 24.12 ± 2.78 | 0.946       |         |
| Body fat (%) | 35.47 ± 4.78 | 34.55 ± 4.83 | 0.038       |         |
| Waist (cm) | 90.68 ± 7.37 | 88.41 ± 8.10 | 0.008       |         |
| Glucose (mg/dL) | 86.62 ± 19.14 | 87.47 ± 18.54 | 0.310       |         |
| HDLC (mg/dL) | 52.14 ± 11.99 | 55.38 ± 13.74 | 0.011       |         |
| TG (mg/dL)  | 129.44 ± 78.82 | 126.16 ± 69.11 | 0.448       |         |
| Systolic BP | 133.34 ± 17.20 | 130.92 ± 15.90 | 0.919       |         |

Metabolic SD

| Metabolic SD | | | OR (95% CI) | p value |
|--------------|-------|---------|-------------|---------|
| Yes | 77 (24.37%) | 239 (75.63%) | 0.924 (0.570, 1.498) | 0.748 |
| No | 112 (19.18%) | 472 (80.82%) |         |         |

BMI, body mass index; HDLC, high density lipoprotein cholesterol; TG, triglyceride; BP, blood pressure. All variables are adjusted for age, smoking status, alcohol consumption, total calcium intake, total energy expenditure, and total calorie intake and variable of Wt (kg) is additionally adjusted by body fat (%), whereas variable of body fat (%) and waist (cm) are adjusted by Wt (kg), respectively.

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**Fig. 1.** Odds ratios of vertebral fractures according to adiposity variables. All variables are adjusted for age, smoking status, alcohol consumption, total calcium intake, total energy expenditure, and total calorie intake and variable of Wt (kg) and BMI are additionally adjusted by body fat (%), whereas variable of body fat (%) and waist (cm) are adjusted by Wt (kg), respectively. BMI: body mass indices.

### DISCUSSION

Both obesity and osteoporosis are common diseases that affect millions of people. In recent decades, the association between obesity and osteoporosis has been actively investigated both from an epidemiological standpoint and from a basic research standpoint, and common pathogenic links have been proposed.\textsuperscript{1-3,6,18} Although it is generally accepted that obesity has a protective effect on bone tissue, some studies have revealed the opposite: that obesity is not beneficial or has a negative effect on osteoporosis.\textsuperscript{21} The relationship between obesity and osteoporosis varies depending on how obesity is defined. If obesity is defined on the basis of BMI or body weight, obesity appears to be a protective factor against bone mineral loss or vertebral fractures. However, if obesity is based on the percentage body fat, obesity
may be a risk factor for osteoporosis. Our data support that body weight is positively related with BMD and a protective factor for vertebral fractures, whereas percentage body fat and waist circumference are negatively related to BMD and a risk factor for vertebral fractures. These results are consistent with those of previous studies in the Chinese population.\textsuperscript{6,7} Some studies have demonstrated that not only lean mass, but also fat mass contribute positively to BMD.\textsuperscript{22-25} In one study, fat mass appeared to contribute inversely to BMD at all sites in young men, but was positively related to BMD at the forearm and calcaneus in older men.\textsuperscript{22} However, the authors of this study did not adjust for body weight when calculating the effect of fat mass on BMD. We found that percentage body fat was positively related to BMD at all sites except the femur ward ($p < 0.001$, data not shown) when not adjusting for body weight. When other variables including body weight were accounted for, this direction became opposite. Waist circumference, which provides an indication of central obesity (visceral fat mass), is related to radius bone mineral density in postmenopausal obese women, although BMI was not related to BMD in the same study.\textsuperscript{26,27} Our data indicate that waist circumference (cm) is related to BMD (Table 2) and osteoporotic vertebral fractures (Table 3).

Metabolic syndrome in relation to osteoporosis has been studied. In the Rancho Bernardo Study, after adjusting for BMI, metabolic syndrome was related to lower BMD.\textsuperscript{28} Furthermore, the incidence of osteoporotic non-vertebral fractures was elevated in subjects with metabolic syndrome (MS). Therefore, metabolic syndrome could be a novel risk factor for osteoporosis. Accumulating evidence suggests that individual components of metabolic syndrome such as hypertension, increased triglycerides, and reduced high-density lipoprotein cholesterol are also risk factors for low bone mineral density.\textsuperscript{29-31} Clinical observations of diabetes patients suggest that hyperglycemia is likely to reduce BMD and to increase the risk of osteoporotic fracture.\textsuperscript{32,33} The high vertebral fracture of diabetes patients can be explained by the fact that they are inclined to fall due to neuropathy or retinopathy. However, we found that serum glucose was positively correlated to lumbar, femur neck, and femur trochanter BMD (Table 2). As we excluded diabetic patients in our study, the average fasting serum glucose level among participating subjects were $87.26 \pm 18.81$ mg/dL. This relatively low glucose level could account for the apparently contradictory results. In another study, serum glucose levels were also positively related to BMD at the lumbar spine and femoral neck in postmenopausal women with primary hyperparathyroidism.\textsuperscript{34} Further investigation is required to evaluate whether serum glucose levels have an effect on bone mineral density and risk of fractures.

The association between lipid profiles and BMD is also controversial. Turkish postmenopausal women with spine fractures had lower levels of total cholesterol, TG, and LDL-C than patients without fractures.\textsuperscript{35} However, another study reported that elevated lipids, including total cholesterol and TG, are positively related to high BMD.\textsuperscript{36} Some studies have demonstrated that high serum HDL is related to lower BMD in both pre- and postmenopausal women.\textsuperscript{37-39} Our data shows that high HDL protects against osteoporosis, increasing BMD, and lowering the odds ratio of osteoporotic fractures (Tables 2 and 3). The mechanism by which lipids affect BMD and the risk of osteoporotic fractures is unclear, and needs to be investigated. The overall prevalence of metabolic syndrome was not related to osteoporotic fractures (Table 3).

Our study has some limitations. To demonstrate that body composition is related to bone mineral density, body fat mass should be analyzed as visceral fat and subcutaneous fat. Peripheral fat mass is not correlated to bone mineral density,\textsuperscript{40} whereas visceral fat (intra-abdominal fat) mass might have a linkage with BMD.\textsuperscript{41} Imaging analysis using CT scans is also essential to evaluate the exact distribution of visceral fat and subcutaneous fat and their effects on bone.\textsuperscript{42} There are possible errors to interpret the effect of fat tissue on low bone mineral density because fat tissue absorbs less radiation than lean tissue, so high percentage fat could yield a false low BMD.\textsuperscript{42}

In conclusion, high body weight and BMI are positively related to high BMD and might decrease the risk of vertebral fractures, whereas waist circumference and percentage body fat are negatively related to BMD and might increase the risk of vertebral fractures. Some components of metabolic syndrome were related to BMD and vertebral fractures. This common clinical linkage between obesity and osteoporosis indicates that co-treatment drugs or nutrients that can prevent and treat these chronic illnesses need to be developed in the future.

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