OBESITY is one of the most important public health problems because of its association with many chronic diseases, including cardiovascular disease, hypertension, type 2 diabetes, dyslipidemia, cancer, and metabolic syndrome [1-4]. Metabolic syndrome is characterized by insulin resistance, as studies have mainly noted insulin resistance in subjects with individual components of metabolic syndrome, such as hypertension, dyslipidemia, and abdominal obesity [5-7]. Many subjects with obesity maintain normal glucose levels because of preservation of the ability to secrete insulin [8]. However, if insulin resistance increases, the ability to secrete insulin decreases, as insulin resistance is one of the factors for the dedifferentiation and death of beta cells [9, 10].

Research on metabolic syndrome and insulin resistance is being conducted all over the world. However, the relationship between metabolic syndrome and beta cell function is not fully understood, and research findings on the association between metabolic syndrome components and beta cell function are not consistent across ethnic groups and countries, healthy subjects, and subjects with disease (e.g., diabetes, obesity) [11-15]. The prevalence of obesity and metabolic syndrome in the Republic of Korea has consistently increased due to the Westernized diet [16]. Therefore, the present study aimed to investigate the relationships of metabolic syndrome and metabolic syndrome score (MSS) with the homeostatic model assessment of beta cell function (HOMA-B) values in adults with obesity, using the fifth Korea National Health and Nutrition Examination Survey (KNHANES V) data, which are representative of the entire population of Korea.
Methods

Study subjects
This study was based on data from the KNHANES V–I (2010), which are the most recent data for HOMA. The KNHANES is a cross-sectional survey conducted nationwide by the Division of Korean National Health and Welfare. The KNHANES V–1 (2010) was performed from January 2010 to December 2010. In the KNHANES V–1 (2010), 8,958 individuals over 1 year of age were sampled for the survey. Among the 6,665 subjects who participated in the KNHANES V–1, we limited the analyses to adults aged ≥20 years. We excluded 4,805 subjects who were in the non-obese group (3,941 subjects, body mass index [BMI] <25.0 kg/m²), and those for whom data were missing for important analytic variables, such as the HOMA-IR, HOMA-B, and various blood chemistry tests (864 subjects). In addition, we excluded subjects with diabetes (174 subjects diagnosed with type 1 or 2 diabetes or with fasting plasma glucose level ≥126 mg/dL). Finally, 1,686 subjects (men, 839; women, 847) were included in the statistical analysis. The KNHANES V–1 (2010) study was conducted according to the principles expressed in the Declaration of Helsinki. (Institutional Review Board No, 2010-02CON-21-C). All participants in the survey provided written informed consent. Further information can be found in “The KNHANES V–1 (2010) Sample,” which is available on the KNHANES website. The data from KNHANES are available on request by email if the applicant logs onto the “Korea National Health and Nutrition Examination Survey” website.

General characteristics and blood chemistry
Research subjects were classified by sex (male or female), smoking (non-smoker, ex-smoker, or current smoker), alcohol drinking (yes or no), and regular exercise (yes or no). In the smoking category, participants who smoked more than one cigarette a day, those who had previously smoked but do not presently smoke, and those who never smoked were classified into the current-smoker, ex-smoker, and non-smoker groups, respectively. Alcohol drinking was indicated as “yes” for participants who had consumed at least one glass of alcohol every month over the last year. Regular exercise was indicated as “yes” for participants who had exercised on a regular basis regardless of indoor or outdoor exercise. Regular exercise was defined as 30 min at a time and 5 times/wk in the case of moderate exercise, such as swimming slowly, doubles tennis, volleyball, badminton, table tennis, and carrying light objects; and for 20 min at a time and 3 times/wk in the case of vigorous exercise, such as running, climbing, cycling fast, swimming fast, football, basketball, jump rope, squash, singles tennis, and carrying heavy objects. Anthropometric measurements included height, weight, BMI, and waist measurement (WM), as well as final measurements of systolic blood pressure (SBP) and diastolic blood pressure (DBP). Blood chemistry included measurement of total cholesterol (TC), high-density lipoprotein cholesterol (HDL-C), triglycerides (TG), fasting plasma glucose (FPG), and 25-hydroxyvitamin D [25(OH)D].

HOMA-IR and HOMA-B and obesity
The homeostatic model assessment of insulin resistance (HOMA-IR) and beta cell function (HOMA-B) constitute a method for assessing beta cell function and IR from basal glucose and insulin concentrations [17]. HOMA-IR and HOMA-B are also significantly associated with diabetes risk across ethnic groups [18]. The formulas are as follows: HOMA-IR = [fasting insulin (μU/mL) × fasting plasma glucose (mg/dL)]/405; HOMA-B = 360 × fasting insulin (μU/mL)/[fasting plasma glucose (mg/dL) − 63] [17]. Obesity was defined as BMI ≥25.0 kg/m² [19].

Metabolic syndrome and MSS
Metabolic syndrome was defined using the diagnostic criteria of the revised National Cholesterol Education Program Adult Treatment Panel III [20], including TG, HDL-C, BP, FPG, and WM. TG over 150 mg/dL or treatment for dyslipidemia were set as the criteria for elevated TG. The criteria for reduced HDL-C were levels less than 40 mg/dL and 50 mg/dL for men and women, respectively, or treatment for dyslipidemia. FPG over 100 mg/dL or the use of medication for hyperglycemia were set as the criteria for elevated FBS. SBP over 130 mmHg or DBP over 85 mmHg or the use of antihypertensive medication were set as the criteria for elevated BP. The criteria for abdominal obesity were abdominal circumference measurements of over 90 cm and 80 cm for men and women, respectively, according to the Asia-Pacific criteria [21]. The presence of defined abnormalities in any 3 of these 5 measures constituted a diagnosis of metabolic syndrome. The MSS indi-
circles the presence of abdominal obesity, elevated BP, elevated FPG, elevated TG, or reduced HDL-C. Subjects without any of the 5 risk factors received an MSS of 0, while those with 1, 2, 3, or 4 or more of the risk factors received an MSS of 1, 2, 3, and ≥4, respectively [22]. In female subjects (n=847), only 27 were classified as MSS 0. Therefore, metabolic syndrome score 0 was combined with MSS 1 and was renamed “MSS ≤1.”

**Comparisons of the HOMA-IR and HOMA-B values according to metabolic syndrome characteristics in men and women**

Comparisons of the HOMA-B values according to metabolic syndrome characteristics in men and women are shown in Table 2. In men, the mean values of HOMA-B were significantly higher in the reduced HDL-C (p=0.008) and abdominal obesity (p=0.001) groups than in the normal group. The mean values of HOMA-B were significantly lower in the elevated BP group (p=0.003) and elevated FPG group (p<0.001) than in the normal group. The mean values of HOMA-IR were significantly higher in all abnormal groups (except the elevated BP group) than in the normal group. In women, the mean value of HOMA-B was significantly higher in the elevated TG group (p=0.012) than in the normal group. The mean value of HOMA-B was significantly lower in the elevated FPG group (p<0.001) than in the normal group. The mean values of HOMA-IR were significantly higher in all abnormal groups than in the normal group.

**Comparisons of the HOMA-IR and HOMA-B values according to metabolic syndrome and MSS in men and women**

Comparisons of the HOMA-IR and HOMA-B values according to metabolic syndrome and MSS in men and women are shown in Tables 3, 4, and 5. Metabolic syndrome and MSS in men and women were positively associated with HOMA-IR values (p<0.001) in both non-adjusted and adjusted models (Table 3). The relationships of HOMA-B values with metabolic syndrome and MSS differed by gender. In men, metabolic syndrome and MSS were not associated with HOMA-B values in models 1, 2, and 3. However, when further adjusted for BMI, metabolic syndrome (p=0.005) and MSS (p=0.018) were inversely associated with HOMA-B values (Table 4). In women, metabolic syndrome and MSS were not associated with HOMA-B values in any of the models (Table 5).

**Discussion**

In our study population of Korean adults with obesity, metabolic syndrome and MSS were not associated with HOMA-B values after adjusting for variables [age, TC, 25(OH)D, smoking, alcohol drinking, and regular exercise]. However, when further adjusted for BMI, metabolic syndrome and MSS were inversely
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Table 2 Comparisons of the HOMA-B and HOMA-IR levels according to metabolic syndrome characteristics in males and females [Mean ± SD (n=1,686)]

| Variables Category | Males (n=839) | Females (n=847) | p |
|--------------------|--------------|-----------------|---|
| Age (years) ≤30    | 284 (33.8)   | 175 (20.7)      | <0.001 |
| 40-49              | 209 (24.9)   | 143 (16.9)      |   |
| 50-59              | 134 (16.0)   | 209 (24.7)      |   |
| ≥60                | 212 (25.3)   | 320 (37.8)      |   |
| Smoking Non-smoker | 141 (16.8)   | 758 (89.5)      | <0.001 |
| Ex-smoker          | 345 (41.1)   | 50 (5.9)        |   |
| Current smoker     | 353 (42.1)   | 39 (4.6)        |   |
| Alcohol drinking No | 192 (22.9) | 547 (64.6)      | <0.001 |
| Yes                | 647 (77.1)   | 300 (35.4)      |   |
| Regular exercise No | 745 (89.2) | 730 (86.2)      | 0.065 |
| Yes                | 94 (10.8)    | 117 (13.8)      |   |
| MetS MSS<3         | 493 (58.8)   | 466 (55.0)      | 0.127 |
| MSS≥3              | 346 (41.2)   | 381 (45.0)      |   |
| MSS ≤1             | 245 (29.2)   | 203 (24.0)      | 0.077 |
| 2                  | 248 (29.6)   | 263 (31.1)      |   |
| 3                  | 214 (25.5)   | 223 (26.3)      |   |
| ≥4                 | 132 (15.7)   | 158 (18.6)      |   |
| Abdominal obesity WM >90 in males or >80 cm in females | 490 (58.4) | 745 (60.3) | <0.001 |
| Elevated blood pressure SBP >135 or DBP >85 mmHg | 447 (53.3) | 389 (45.9) | 0.003 |
| Elevated triglyceride TG >150 mg/dL | 407 (48.5) | 254 (30.0) | <0.001 |
| Reduced HDL-C HDL-C <40 in males or <50 mg/dL in females | 220 (26.2) | 401 (47.3) | <0.001 |
| Elevated FPG FPG >100 mg/dL | 297 (35.4) | 255 (30.1) | 0.021 |
| BMI (kg/m²) 27.08 ± 1.99 | 27.55 ± 2.42 | <0.001 |
| Insulin (μU/mL) 12.16 ± 5.18 | 12.41 ± 5.70 | 0.338 |
| HOMA-IR 2.94 ± 1.39 | 2.96 ± 1.49 | 0.713 |
| HOMA-B 137.91 ± 67.84 | 146.35 ± 78.39 | 0.018 |

MetS, Metabolic syndrome; MSS, Metabolic syndrome score; WM, waist measurement; BMI, body mass index; SBP, systolic blood pressure; DBP, diastolic blood pressure; TG, triglyceride; HDL-C, high density lipoprotein cholesterol; FPG, fasting plasma glucose; BMI, body mass index; HOMA-IR, Homeostasis model assessment of insulin resistance; HOMA-B, Homeostasis model assessment of beta cell function.

Table 1 General characteristics of research subjects [n (%), Mean ± SD (n=1,686)]

| Variables | Males (n=839) | Females (n=847) | p |
|-----------|--------------|-----------------|---|
| Age (years) | ≤30 | 284 (33.8) | 175 (20.7) | <0.001 |
| 40-49      | 209 (24.9) | 143 (16.9) |   |
| 50-59      | 134 (16.0) | 209 (24.7) |   |
| ≥60        | 212 (25.3) | 320 (37.8) |   |
| Smoking    | Non-smoker | 141 (16.8) | 758 (89.5) | <0.001 |
| Ex-smoker  | 345 (41.1) | 50 (5.9) |   |
| Current smoker | 353 (42.1) | 39 (4.6) |   |
| Alcohol drinking | No | 192 (22.9) | 547 (64.6) | <0.001 |
| Yes        | 647 (77.1) | 300 (35.4) |   |
| Regular exercise | No | 745 (89.2) | 730 (86.2) | 0.065 |
| Yes        | 94 (10.8) | 117 (13.8) |   |
| MetS MSS<3 | 493 (58.8) | 466 (55.0) | 0.127 |
| MSS≥3      | 346 (41.2) | 381 (45.0) |   |
| MSS ≤1     | 245 (29.2) | 203 (24.0) | 0.077 |
| 2          | 248 (29.6) | 263 (31.1) |   |
| 3          | 214 (25.5) | 223 (26.3) |   |
| ≥4         | 132 (15.7) | 158 (18.6) |   |
| Abdominal obesity WM >90 in males or >80 cm in females | 490 (58.4) | 745 (60.3) | <0.001 |
| Elevated blood pressure SBP >135 or DBP >85 mmHg | 447 (53.3) | 389 (45.9) | 0.003 |
| Elevated triglyceride TG >150 mg/dL | 407 (48.5) | 254 (30.0) | <0.001 |
| Reduced HDL-C HDL-C <40 in males or <50 mg/dL in females | 220 (26.2) | 401 (47.3) | <0.001 |
| Elevated FPG FPG >100 mg/dL | 297 (35.4) | 255 (30.1) | 0.021 |
| BMI (kg/m²) 27.08 ± 1.99 | 27.55 ± 2.42 | <0.001 |
| Insulin (μU/mL) 12.16 ± 5.18 | 12.41 ± 5.70 | 0.338 |
| HOMA-IR 2.94 ± 1.39 | 2.96 ± 1.49 | 0.713 |
| HOMA-B 137.91 ± 67.84 | 146.35 ± 78.39 | 0.018 |

MetS, Metabolic syndrome; MSS, Metabolic syndrome score; WM, waist measurement; BMI, body mass index; SBP, systolic blood pressure; DBP, diastolic blood pressure; TG, triglyceride; HDL-C, high density lipoprotein cholesterol; FPG, fasting plasma glucose; BMI, body mass index; HOMA-IR, Homeostasis model assessment of insulin resistance; HOMA-B, Homeostasis model assessment of beta cell function.

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- Normal is defined as WM <90 cm in males or <80 cm in females.
- Abdominal obesity is defined as WM ≥90 cm in males or ≥80 cm in females.
- Normal is defined as SBP <130 mmHg or DBP <85 mmHg.
- Elevated blood pressure is defined as SBP ≥130 mmHg or DBP ≥85 mmHg.
- Normal is defined as TG <150 mg/dL.
- Elevated triglyceride is defined as TG ≥150 mg/dL.
- Normal is defined as HDL-C ≥40 mg/dL in males or ≥50 mg/dL in females.
- Reduced HDL-C is defined as HDL-C <40 mg/dL in males or <50 mg/dL in females.
- Normal is defined as FPG <100 mg/dL.
- Elevated FPG is defined as FPG ≥100 mg/dL.
Table 3  Comparisons of the HOMA-IR Levels according to metabolic syndrome and MSS in males and females (n=1,686)

|         | Males (n=839) | Females (n=847) |
|---------|---------------|------------------|
|         | Non-adjusted  | * Adjusted       | Non-adjusted  | * Adjusted       |
|         | (M ± SE, 95% CI) | (M ± SE, 95% CI) | (M ± SE, 95% CI) | (M ± SE, 95% CI) |
| MSS     |               |                  |               |                  |
| ≤1      | 2.29 ± 0.08 (2.12-2.45) | 2.43 ± 0.08 (2.26-2.59) | 2.34 ± 0.10 (2.14-2.53) | 2.42 ± 0.10 (2.22-2.61) |
| 2       | 2.89 ± 0.08 (2.73-3.05) | 2.87 ± 0.08 (2.72-3.03) | 2.82 ± 0.09 (2.65-2.99) | 2.80 ± 0.08 (2.63-2.96) |
| 3       | 3.26 ± 0.09 (3.08-3.43) | 3.18 ± 0.09 (3.01-3.35) | 3.21 ± 0.10 (3.02-3.40) | 3.17 ± 0.09 (2.99-3.35) |
| >4      | 3.73 ± 0.11 (3.51-3.95) | 3.62 ± 0.11 (3.40-3.83) | 3.66 ± 0.11 (3.44-3.88) | 3.65 ± 0.11 (3.44-3.87) |
| p       | <0.001        | <0.001           | <0.001        | <0.001           |

Non-MetS | 2.59 ± 0.06 (2.47-2.71) | 2.66 ± 0.06 (2.55-2.78) | 2.61 ± 0.07 (2.48-2.74) | 2.65 ± 0.07 (2.52-2.77) |

MetS    | 3.44 ± 0.07 (3.30-3.58) | 3.33 ± 0.07 (3.19-3.47) | 3.40 ± 0.07 (3.25-3.54) | 3.36 ± 0.07 (3.21-3.50) |
| p       | <0.001        | <0.001           | <0.001        | <0.001           |

MSS, Metabolic syndrome score; Non-MetS, Non-metabolic syndrome; MetS, Metabolic syndrome. * Adjusted for age, smoking, alcohol drinking, regular exercise, and BMI.

Table 4  Comparisons of the HOMA-B Levels according to metabolic syndrome and MSS in males (n=839)

|         | Model 1 [M ± SE (95% CI)] | Model 2 [M ± SE (95% CI)] | Model 3 [M ± SE (95% CI)] | Model 4 [M ± SE (95% CI)] |
|---------|---------------------------|----------------------------|---------------------------|---------------------------|
| MSS     |                           |                            |                           |                           |
| ≤1      | 142.21 ± 4.32 (133.73-150.70) | 138.00 ± 4.28 (129.60-146.40) | 137.86 ± 4.27 (129.47-146.25) | 147.77 ± 4.30 (136.33-153.21) |
| 2       | 142.30 ± 4.30 (133.86-150.73) | 142.62 ± 4.20 (134.38-150.87) | 143.01 ± 4.18 (134.82-151.21) | 142.24 ± 4.08 (134.25-150.24) |
| 3       | 135.53 ± 4.63 (126.45-144.61) | 137.41 ± 4.53 (128.52-146.31) | 137.13 ± 4.53 (128.24-146.01) | 133.74 ± 4.45 (125.01-142.46) |
| ≥4      | 125.52 ± 5.89 (113.95-137.08) | 129.67 ± 5.79 (118.29-141.04) | 129.6 ± 5.76 (118.36-140.96) | 123.79 ± 5.69 (112.62-134.95) |
| p       | 0.082                     | 0.349                      | 0.312                     | 0.018                     |

Non-MetS | 142.25 ± 3.05 (136.27-148.24) | 140.34 ± 2.99 (134.46-146.21) | 140.49 ± 2.98 (134.64-146.35) | 143.40 ± 2.94 (137.62-149.18) |

MetS    | 131.71 ± 3.64 (124.57-138.85) | 134.44 ± 3.58 (127.41-141.47) | 134.22 ± 3.57 (127.21-141.23) | 130.07 ± 3.54 (123.12-137.03) |
| p       | 0.027                     | 0.209                      | 0.182                     | 0.005                     |

MSS, Metabolic syndrome score; Non-MetS, Non-metabolic syndrome; MetS, Metabolic syndrome. Model 1 [M ± SE (95% CI)], Non-adjusted; Model 2 [M ± SE (95% CI)], adjusted for age; Model 3 [M ± SE (95% CI)], adjusted for age, smoking, alcohol drinking, and regular exercise; Model 4 [M ± SE (95% CI)], adjusted for age, smoking, alcohol drinking, regular exercise, and BMI.

Table 5  Comparisons of the HOMA-B Levels according to metabolic syndrome and metabolic syndrome scores in females (n=847)

|         | Model 1 [M ± SE (95% CI)] | Model 2 [M ± SE (95% CI)] | Model 3 [M ± SE (95% CI)] | Model 4 [M ± SE (95% CI)] |
|---------|---------------------------|----------------------------|---------------------------|---------------------------|
| MSS     |                           |                            |                           |                           |
| ≤1      | 148.84 ± 5.51 (138.03-159.65) | 141.62 ± 5.60 (130.63-152.61) | 142.71 ± 5.58 (131.75-153.66) | 146.96 ± 5.59 (135.99-157.94) |
| 2       | 149.38 ± 4.84 (139.89-158.89) | 147.89 ± 4.77 (138.51-157.26) | 148.07 ± 4.76 (138.74-157.41) | 148.01 ± 4.70 (138.79-157.23) |
| 3       | 143.11 ± 5.26 (132.79-153.42) | 146.38 ± 5.21 (136.14-156.61) | 145.62 ± 5.20 (135.42-155.82) | 143.46 ± 5.16 (133.34-153.58) |
| ≥4      | 142.65 ± 6.24 (130.40-154.91) | 149.83 ± 6.30 (137.46-162.20) | 149.18 ± 6.28 (136.86-161.50) | 146.87 ± 5.16 (133.34-153.58) |
| p       | 0.722                     | 0.780                      | 0.857                     | 0.929                     |

Non-MetS | 149.15 ± 3.63 (142.03-156.28) | 145.28 ± 3.66 (138.11-152.46) | 145.85 ± 3.65 (138.70-153.01) | 147.61 ± 3.62 (140.50-154.71) |

MetS    | 142.92 ± 4.02 (135.04-150.80) | 147.65 ± 4.06 (139.67-155.63) | 146.95 ± 4.05 (138.99-154.91) | 144.81 ± 4.03 (136.90-152.72) |
| p       | 0.250                     | 0.672                      | 0.844                     | 0.616                     |

MSS, Metabolic syndrome score; Non-MetS, Non-metabolic syndrome; MetS, Metabolic syndrome. Model 1 [M ± SE (95% CI)], Non-adjusted; Model 2 [M ± SE (95% CI)], adjusted for age; Model 3 [M ± SE (95% CI)], adjusted for age, smoking, alcohol drinking, and regular exercise; Model 4 [M ± SE (95% CI)], adjusted for age, smoking, alcohol drinking, regular exercise, and BMI.
associated with HOMA-B values in men, but not in women (Tables 4 and 5).

In our study, the prevalence of metabolic syndrome (46.9%) in populations with obesity was higher than that in a previous report by Chung et al. [23], and lower than that previously reported by Hsiao et al. [24], but it was similar to that in a previous report by Gobato et al. [25]. Currently, research on the association between beta cell function and the increase of metabolic syndrome components is lacking. Baez-Duarte et al. reported the progressive deterioration of beta cell function and insulin sensitivity in subjects with metabolic syndrome as the number of features of metabolic syndrome increased in Mexican subjects [11]. Cubeddu et al. reported that beta cell function and insulin sensitivity were inversely associated with a number of traits of metabolic syndrome in apparently healthy Latin-American subjects [12]. In addition, Garg et al. reported that increasing numbers of metabolic abnormalities were inversely associated with HOMA-B values in adults in the United States [26]. In the present study, the HOMA-B values in men were significantly lower in the elevated BP and elevated FPG groups than in the normal group, but the HOMA-B values of the abdominal obesity and reduced HDL-C groups were significantly higher than that of the normal group. In addition, when adjusted for relevant variables (except BMI), metabolic syndrome and MSS were not independently associated with HOMA-B. However, when further adjusted for BMI, both metabolic syndrome and MSS were inversely associated with HOMA-B. In the present study, the HOMA-B values in men were significantly lower in the elevated BP and elevated FPG groups than in the normal group, but the HOMA-B values of the abdominal obesity and reduced HDL-C groups were significantly higher than that of the normal group. In addition, when adjusted for relevant variables (except BMI), metabolic syndrome and MSS were not independently associated with HOMA-B. However, when further adjusted for BMI, both metabolic syndrome and MSS were inversely associated with HOMA-B. Metabolic syndrome is characterized by insulin resistance [5], and metabolic syndrome risk factors are strongly associated with oxidative stress or the elevated circulating concentration of free fatty acids [27]. Oxidative stress increases in response to the increased production of reactive oxygen species and the decrease of antioxidant enzymes. In addition, endoplasmic reticulum stress is caused by prolonged high insulin production or lipid molecules, such as free fatty acids [9]. The dedifferentiation and death of beta cells are caused by insulin resistance [11], oxidative stress [28], and increased endoplasmic reticulum (ER) stress [29]. In healthy subjects, a compensatory increase of beta cell function may occur [30], but subjects in the present study were obese populations. Obesity is a chronic disease and is associated with insulin resistance-related disorders such as oxidative stress, ER stress, dyslipidemia, and hypertension [31]. There is a possibility that long-term exposure to this disease, and it is possible not appears these compensatory mechanisms in the obese population. In addition, obesity is the one of the factors responsible for type 2 diabetes mellitus. However, in order to develop into hyperglycemia, the body must fail to produce sufficient insulin, and this is associated with the pancreatic beta cells. Even in individuals with obesity, in the absence of insulin resistance, pancreatic beta cells are activated to secrete insulin when blood glucose increases [32, 33]. However, the function or mass of beta cells is significantly reduced in subjects with insulin resistance, such as type 2 diabetes mellitus and metabolic syndrome [34, 35]. In previous studies [36, 37], decreases in beta cell mass were mainly seen in subjects with insulin resistance, implying that this is caused by an increase in pancreatic beta cell apoptosis, necrosis, or autophagy in the state of insulin resistance.

On the other hand, after adjusting for relevant variables in women (by including or excluding BMI), both metabolic syndrome and MSS were not independently associated with HOMA-B. The mechanisms underlying the gender difference in the relationship between metabolic syndrome and beta cell function have not yet been defined. This association may be due to sex hormones such as estrogens. Estrogens, involving estrogen receptor alpha (ER-α) and beta (ER-β), are associated with the homeostasis of blood glucose, as well as the control of body fat distribution and adipose tissue metabolism [38-40]. In particular, estradiol (E2) is involved in maintaining normal insulin sensitivity and is beneficial for beta cell function [41], and ER-α has a crucial role in increasing proinsulin biosynthesis in response to physiological concentrations of E2 [42]. Moreover, ER-α plays an important role in the regulation of insulin secretion, pancreatic β-cell survival, and obesity [42]. Previous studies suggested that ER-α may play an important role in fat metabolism and obesity [42, 43]. In addition, in the study by Heine et al., ER-α knockout mice were obese and insulin resistant [44]. In our results, metabolic syndrome and increasing MSS were associated with the reduction of beta cell function in men, but not in women. We cannot verify these results because the KNHANES V-1 did not measure estrogen, but we think that these results are due to estrogens.

Some studies have suggested that the relationship between beta cell function and metabolic syndrome
might not be direct, and that these relationships might be caused by factors such as differences in genetic background, dietary habits, and physical activities [45, 46]. Thus, they implied that the association between metabolic syndrome and beta cell function is not consistent according to ethnicity and country. However, these inconsistencies may be attributed to differences in measurements of beta cell function (e.g., clamp studies, the Intravenous Glucose Tolerance Test [IVGTT], Insulin Secretion-Sensitivity Index [ISSI], insulin sensitivity derived from an oral glucose tolerance test [ISOGTT], or HOMA indices). Although HOMA indices are not the “gold-standard” method (e.g., hyperinsulinemic-euglycemic clamp and the hyperglycemic clamp test), HOMA may be more appropriate for use in large epidemiological studies [47]. In addition, one of the difficulties in conducting the extensive research required to determine the clinical utility of measures of insulin resistance, sensitivity, and secretion is the lack of standardized insulin assays. Results reported from one study to the next are not comparable, which makes only qualitative comparisons between studies possible [48]. Therefore, the introduction of a sustainable insulin assay standardization program is necessary.

The present study has a few limitations. First, because this study was a cross-sectional study, the ability to establish a causal relationship between metabolic syndrome and increased levels of its components and beta cell dysfunction was limited. Second, KNHANES data are representative national data in Korea. However, considering the sample size and study population, this study has limitations for generalization. Nevertheless, this is the first reported study to determine the relationship between metabolic syndrome and the increased levels of its components and HOMA-B levels by gender in Korean adults with obesity. Therefore, more accurate results might be obtained by performing a cohort study.

We conclude that the relationship between metabolic syndrome and MSS and beta cell function in Korean adults with obesity were different according to gender. Metabolic syndrome and MSS increases were inversely associated with beta cell function in Korean men with obesity, but not in Korean women with obesity.

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Disclosure

The authors declare that there is no conflict of interest associated with this manuscript.

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