Prevalence of Metabolic Syndrome and Obesity in Adolescents Aged 12 to 19 Years: Comparison between the United States and Korea

This study compared the prevalence of metabolic syndrome (MetS), its risk factors, and obesity in adolescents in the United States (US) and Korea. Data were obtained from 2003-2004 US National Health and Nutrition Examination Survey (NHANES) and 2005 Korea NHANES for adolescents aged 12-19 yr in the US (n=734) and in Korea (n=664). The 2007 International Diabetes Federation (IDF) pediatric definition for diagnosis of MetS and the 2000 US Growth Charts and 2007 Korea Growth Charts for assessment of obesity were utilized. The prevalence of metabolic syndrome in US and Koreans was 5.5% and 2.5%, respectively. The prevalence of obesity was 18.1% in US compared to 9.0% in Koreans. The prevalence of abdominal obesity, hyperglycemia, and hypertriglyceridemia were higher in the US, whereas that of low HDL-C levels was higher in Korea. Despite the doubled prevalence for the single entities of MetS and obesity in the US, the prevalence of MetS in obese US and Koreans did not differ (20.8% and 24.3%, respectively). In conclusion, there are differences in the prevalence of MetS, obesity, and the individual MetS risk factors between the US and Korean adolescents; however, the risk of MetS among obese adolescents is similar in both countries.

Key Words : *Adolescents; Obesity; Metabolic Syndrome; National Health and Nutrition Examination Survey; United States; Korea; International Diabetes Federation; Growth Charts*

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INTRODUCTION

Obesity is generally recognized as an increasingly important cause of childhood and adolescent morbidity worldwide and is a contributor to chronic diseases such as type 2 diabetes and cardiovascular disease (CVD) (1). The metabolic syndrome (MetS), a clustering of obesity, impaired glucose metabolism, hypertension, and dyslipidemia, has been shown to be predictive for the development of diabetes and CVD in this young population, particularly in the overweight or obese (2). MetS has appeared with increasing frequency in children and adolescents, driven by the growing pediatric obesity epidemic (1).

Behavioral factors such as poor dietary habits, a sedentary lifestyle, and a social environment which encourages unhealthy behaviors are closely correlated with the prevalence of obesity and MetS in adolescents (3). During adolescence developmental physiologic changes in body composition, lipid pro-file, blood pressure, insulin secretion and number of body fat cells occur as a result of higher levels of sex and growth hormones. This results in increased insulin resistance that is associated with MetS. Therefore, the convergence of hormonal changes associated with adolescence and unhealthy lifestyle behaviors can predispose this group to MetS and obesity and a risk of adverse CVD events later in life (3).

Although obesity in children and adolescents has been widely studied, MetS has not because a consensus on pediatric MetS criteria did not exist until recently (4). In order to fill this gap, the International Diabetes Federation (IDF) published the first international definition of the pediatric MetS in 2007 (4), facilitating comparisons between pediatric populations (5). The IDF advocates waist circumference (WC) as a key diagnostic component of pediatric MetS (4) as in the adult definition. Comparisons for adolescents of different countries, ethnicities, and genders should be published to evaluate international criteria for MetS like the 2007 IDF defini-

tion. Using the IDF definition as a starting point, modifications can be made on the basis of new information (4).

Most studies in adolescents have been limited to Western countries and infrequently included Asians (6, 7). Asians, on average, have a lower body mass than Western populations and their traditional diets and lifestyle are not commonly associated with obesity or CVD risk. However, the incidence of obese children and adolescents has been increasing in Korea, as has urbanization and economic development. Accompanying these changes is the adoption of a westernized diet and a trend toward decreased physical activity (8). As young Asian individuals continue to adopt Western lifestyles, it is important to predict the types of population-based health consequences that might follow. Our study had three main hypotheses: 1) US adolescents have a higher prevalence of obesity and MetS than Korean adolescents; 2) individual abnormalities of MetS differ between US and Korean adolescents; and 3) Korean adolescents have an equal or greater prevalence of MetS when compared to US adolescents of the same BMI category, since Asians have a higher risk of type 2 diabetes and CVD at lower BMI's than European populations (9). By comparing the differences in the prevalence of MetS and obesity in US and Korean adolescents using the latest national datasets, we set out to provide guidance both to countries whose population is starting to embrace Western lifestyles and to Western societies who wish to reduce the high burden of complications from these conditions.

MATERIALS AND METHODS

Data source and subjects

This study was based on data from the 2003-2004 US National Health and Nutrition Examination Surveys (NHANES) (10) and the 2005 Korean NHANES (KNHANES) (11). Both were cross-sectional nationally representative surveys of the US and Korean civilian non-institutionalized populations, and used standardized protocols within each survey for all interviews and medical examinations (10, 11). Subjects selected from the US NHANES were Mexican-Americans, non-Hispanic Whites, and non-Hispanic Blacks and from the KNHANES were Koreans. The subjects from both data sets were limited to young men and non-pregnant women aged 12 to 19 yr who participated in the medical examination of NHANES and KNHANES and who had fasted at least 8 hr prior to the blood collection. Only subjects who had all five indicators of MetS measured according to IDF criteria were included in the study. Samples of 734 (414 male) and 664 (359 male) subjects from the US and Korean NHANES, respectively, were used in the analyses, and the estimated US and Korean population represented by each sample was 25.5 million and 4.4 million, respectively. The proportion of ethnicities that comprised the entire US sample

population in this study was Mexican-Americans 12.2±3.5%, non-Hispanic Whites 72.5±4.6%, and non-Hispanic Blacks 15.2±2.5%, respectively.

US NHANES and Korean NHANES methodologies have been described in detail elsewhere (10, 11). Socio-demographic data were collected by personal interview.

Anthropometric indices such as height, weight, and waist circumference were also extracted from each database, and body mass index (BMI) was calculated from height and weight. The data was obtained in a similar manner in each study. Height was measured in an upright position with a stadiometer, and weight was measured at a standing position on a self-zeroing scale. Waist circumference was measured at the midpoint between the bottom of the rib cage and above the top of the iliac crest during minimal respiration. Laboratory indices and blood pressure were also collected by a standard protocol, and the mean of the 2nd and 3rd systolic and diastolic blood pressure (SBP and DBP) readings were used for this study. Pulse pressure was defined as the difference between SBP and DBP. For both surveys, fasting blood glucose (FBG) was measured indirectly by spectrophotometry after an enzymatic reaction, and triglycerides (TG) were indirectly determined by spectrophotometry after hydrolyzation to glycerol and two-stage enzymatic reactions. High density lipoprotein cholesterol (HDL-C) was indirectly measured by spectrophotometry after precipitation with sulfated alpha-cyclodextrin and a two-stage enzymatic reaction. Low density lipoprotein cholesterol (LDL-C) was calculated using the Friedewald equation (serum total cholesterol (TC)-(HDL-C)-TG/5) after eliminating those who had TG greater than 400 mg/dL (12).

Definition of MetS and obesity

Because of the profound physiological and developmental changes during puberty, the 2007 pediatric IDF definition of MetS (4) divided children and adolescents into the following age groups: 6 to <10, 10 to <16, and ≥16 yr. According to this definition, the adult IDF guidelines for the MetS were applied to adolescents 16 years or older, and the KSSO, a Korean-specific criterion (13), was used for Korean waist circumference (WC). In individuals aged 10-15 yr, MetS is present if he or she has central adiposity (≥90th WC percentile or adult threshold if lower) plus at least two of the following criteria: 1) TG ≥150 mg/dL, 2) HDL-C <40 mg/dL, 3) SBP ≥130 mmHg or DBP ≥85 mmHg, 4) FBG ≥100 mg/dL or previously diagnosed type 2 diabetes. For US males aged 12-15 yr, we used adult WC thresholds of 90 cm for Mexican Americans and 94 cm for Whites and African Americans since these were smaller than the corresponding 90th percentiles for age. For US females of all ages, we used the adult threshold of 80 cm because it was smaller than their 90th percentile for age. For Korean males and females aged 12-15 yr, we used the WC thresholds (sex- and age-specific 90th percentiles) derived from the reference WC in the 2007

Korea Growth Charts instead of the recommended adult IDF threshold criteria which was larger than their 90th percentiles for age.

To evaluate the prevalence of obesity and MetS by BMI levels, subjects were classified into three BMI categories (normal weight, overweight, and obese) using the 2000 US Growth Charts (14) and the 2007 Korea Growth Charts (15). The analyses by this classification were applied only to individuals aged 12-18 yr because the Korean Growth Charts do not go beyond 18 yr. Obesity was defined as a BMI ≥95th percentile for age and gender; adolescents with a BMI ≥85th but <95th percentile were defined as "overweight;" and participants defined as "normal weight" had a BMI from the 5th to the 85th percentile (14, 15).

Statistical methods

Statistical analyses were performed using SAS (version 9.1.3, SAS Institute, Inc., Cary NC, USA) and SAS-callable SUDAAN (version 9.0.3, Research Triangle Institute, Research Triangle Park, NC, USA). In order to make a statistical comparison between the two countries, selected variables from the 2003-4 US and 2005 Korean datasets were merged and the combined data was used in all analyses. Data in all statistical analyses for our study were weighted to account for the complex sampling design of both NHANES which were multistage, stratified, unequally weighted, or clustered. Appropriate statistical sampling weights from each national dataset were selected as specified by the respective survey. Estimat-ed frequencies of categorical variables and mean and standard error of continuous variables between the two countries were compared by the chi-square and t-test procedures of SUDAAN. Each national sample weight was applied after data from the two countries were merged into a single file by creating a new variable. These statistics were presented as mean ±standard error (SE) for continuous variables and frequency percentage (SE) for all categorical measures. A P value <0.05 was considered statistically significant.

RESULTS

Table 1 shows anthropometric and clinical measurements for US and Korean adolescents. Overall, height, weight, and BMI in the US were significantly higher than in Korean adolescents (all, P<0.001). The US adolescents had significantly higher FBG and TC than Korean adolescents (both, P<0.001). However, LDL-C:HDL-C and TC:HDL-C ratios were significantly higher in Korean adolescents than in the US (both, P<0.001) resulting from lower HDL-C (P<0.001) and higher LDL-C (P<0.05) of Koreans. SBP was higher in the US (P<0.01), while DBP was higher in Korean adolescents (P<0.001); however, pulse pressure was significantly higher in the US by about 10 mmHg (P<0.001). Concentrations of TG did not differ between the two countries.

The prevalence of MetS and its components in US and Korean adolescents according to the 2007 IDF definition is presented in Table 2. The prevalence of MetS in US adoles-

Table 1. Weighted average values of the anthropometric, biochemical indicators, and blood pressure in adolescents: The US NHANES 2003-04, Korea NHANES 2005

Parameters	US			Korea		
	Males (n=414, 13.4 m)[§]	Females (n=320, 12.1 m)	Total (n=734, 25.5 m)	Males (n=359, 2.4 m)	Females (n=305, 2.0 m)	Total (n=664, 4.4 m)
Anthropometric						
Height (cm)	172.9±0.8	162.3±0.7	167.8±0.6	168.0±0.5[‡]	159.5±0.4[‡]	164.1±0.4[‡]
Weight (kg)	71.9±1.1	62.7±1.6	67.5±1.0	61.1±0.8[‡]	53.6±0.6[‡]	57.7±0.5[‡]
Body Mass Index (kg/m²)	23.8±0.3	23.8±0.6	23.8±0.3	21.5±0.2[‡]	21.0±0.2[‡]	21.3±0.2[‡]
Waist circumference (cm)	83.4±0.9	81.5±1.3	82.5±0.8	73.6±0.6[‡]	68.4±0.5[‡]	71.2±0.5[‡]
Biochemical						
Fasting blood glucose (mg/dL)	93.9±1.2	88.4±0.8	91.3±0.8	88.1±0.4[‡]	85.8±0.4[†]	87.0±0.3[‡]
Triglycerides (mg/dL)	97.8±4.1	90.1±5.8	94.2±3.5	90.9±2.9	85.7±2.3	88.5±2.1
HDL-cholesterol, HDL-C (mg/dL)	48.5±0.8	56.2±0.9	52.2±0.4	41.7±0.5[‡]	46.6±0.6[‡]	43.9±0.4[‡]
LDL-cholesterol, LDL-C (mg/dL)	88.8±1.5	90.2±1.5	89.4±1.2	90.2±1.4	96.3±1.2[†]	93.0±0.9*
Total cholesterol, TC (mg/dL)	156.6±2.1	164.9±2.4	160.5±1.7	150.1±1.7*	159.8±1.5[‡]	154.5±1.1[‡]
LDL-C:HDL-C	1.94±0.04	1.71±0.05	1.83±0.04	2.22±0.03[‡]	2.13±0.03[‡]	2.18±0.02[‡]
TC:HDL-C	3.39±0.05	3.08±0.07	3.24±0.05	3.69±0.04[‡]	3.53±0.04[‡]	3.62±0.03[‡]
Blood pressure						
Systolic blood pressure, SBP (mmHg)	112.7±0.6	105.7±0.7	109.4±0.6	110.1±0.8[†]	103.7±0.6*	107.2±0.6[†]
Diastolic blood pressure, DBP (mmHg)	59.5±1.1	62.4±0.7	60.9±0.8	70.2±0.7[‡]	67.4±0.6[‡]	68.9±0.5[‡]
Pulse pressure, SBP-DBP	53.3±1.1	43.3±0.7	48.5±0.8	39.8±0.7[‡]	36.4±0.5[‡]	38.3±0.5[‡]

Data are mean±SE. *P<0.05; [†]P<0.01; [‡]P<0.001 show significant differences between the US and Korea; [§]n, sample size (estimated population represented in millions).

Table 2. Estimated prevalence of metabolic syndrome, individual components, and distribution according to the number of metabolic abnormalities by IDF (2007) criteria: the US NHANES 2003-04, Korea NHANES 2005

Parameters	US			Korea		
	Males (n=414, 13.4 m)[§]	Females (n=320, 12.1 m)	Total (n=734, 25.5 m)	Males (n=359, 2.4 m)	Females (n=305, 2.0 m)	Total (n=664, 4.4 m)
Prevalence of metabolic syndrome and its components						
MetS[‖]	7.3 (1.7)	3.5 (0.9)	5.5 (0.9)	3.6 (1.0)	1.2 (0.6)*	2.5 (0.6)[†]
Abdominal obesity	24.4 (2.2)	46.1 (3.7)	34.7 (2.2)	9.2 (1.5)[‡]	7.5 (1.6)[‡]	8.4 (1.1)[‡]
Hyperglycemia	16.9 (2.5)	6.2 (1.7)	11.8 (1.9)	2.5 (0.8)[‡]	3.6 (1.2)	3.0 (0.7)[‡]
Hypertriglyceridemia	17.2 (3.4)	10.9 (3.4)	14.2 (1.7)	9.7 (1.6)*	4.5 (1.2)	7.3 (1.1)[†]
Low HDL-C	22.9 (2.5)	20.2 (3.3)	21.6 (1.9)	42.9 (3.3)[‡]	38.9 (3.1)[‡]	41.1 (2.2)[‡]
High BP	6.4 (1.9)	1.5 (1.1)	4.1 (1.1)	8.7 (1.8)	3.0 (1.2)	6.1 (1.2)
The number of metabolic abnormalities (not considering abdominal obesity)						
1≤	53.1 (3.0)	60.4 (3.3)	56.5 (1.8)	52.1 (3.2)	45.7 (2.9)[†]	49.2 (2.2)*
2≤	22.0 (2.6)	20.5 (3.7)	21.3 (2.0)	16.2 (2.0)	10.1 (1.8)*	13.4 (1.4)[†]
3≤	7.3 (1.6)	3.5 (0.9)	5.5 (0.9)	4.3 (1.1)	1.2 (0.6)*	2.9 (0.7)*
4≤	4.2 (1.5)	0.3 (0.3)	2.4 (0.8)	0.4 (0.4)*	0.6 (0.4)	0.5 (0.3)*
5	1.2 (0.8)	0.1 (0.1)	0.7 (0.4)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)

Data are % (SE). *$P<0.05$; [†]$P<0.01$; [‡]$P<0.001$ show significant differences between the US and Korea; [§]n, sample size (estimated population represented in millions); [‖]MetS, Metabolic Syndrome: IDF definition is described in 'MATERIALS AND METHODS'.

Table 3. Estimated prevalence of obesity by 2000 US Growth Charts and 2007 Korea Growth Charts: the US NHANES 2003-04, Korea NHANES 2005

	US			Korea		
	Males (n=414, 13.4 m)[†]	Females (n=320, 12.1 m)	Total (n=734, 25.5 m)	Males (n=359, 2.4 m)	Females (n=305, 2.0 m)	Total (n=664, 4.4 m)
5th≤ <85th (normal weight)	60.8 (4.2)	60.7 (4.7)	60.8 (3.2)	78.4 (2.8)*	79.9 (2.8)*	79.1 (2.0)*
85th≤ <95th (overweight)	17.2 (4.3)	25.4 (3.0)	21.1 (2.5)	12.3 (2.0)*	11.6 (2.3)*	12.0 (1.5)*
95th≤ (obese)	22.0 (2.6)	13.9 (4.9)	18.1 (3.2)	9.3 (2.1)*	8.5 (2.0)*	9.0 (1.5)*

Data are % (SE). *$P<0.001$ show significant differences between the US and Korea; [†]n, sample size (estimated population represented in millions).

cents was $5.5\pm0.9\%$ (males $7.3\pm1.7\%$, females $3.5\pm0.9\%$), which is more than twice the prevalence for Korean adolescents, $2.5\pm0.6\%$ (males $3.6\pm1.0\%$, females $1.2\pm0.6\%$, $P<0.01$). Based on population-weighted estimates, it can be calculated that -1.4 million US and 0.1 million Korean adolescents aged 12-19 yr have MetS according to the 2007 IDF pediatric criteria.

The prevalence of abdominal obesity ($P<0.001$), hyperglycemia ($P<0.001$), and hypertriglyceridemia ($P<0.01$) in the US were significantly higher than in Korean adolescents, while the prevalence of a low HDL-C level was significantly higher in Korean adolescents ($P<0.001$). There was a striking difference in the prevalence of abdominal obesity by gender; the prevalence in American males was more than double the prevalence in Korean males (US $24.4\pm2.2\%$ vs. Korea $9.2\pm1.5\%$). American females had more than six times the prevalence found in Korean females (US $46.1\pm3.7\%$ vs. Korea $7.5\pm1.6\%$). US males had nearly seven times the prevalence of hyperglycemia (US $16.9\pm2.5\%$ vs. Korea $2.5\pm0.8\%$) and twice the prevalence of hypertriglyceridemia (US $17.2\pm3.4\%$ vs. Korea $9.7\pm1.6\%$). The prevalence of elevated

blood pressure did not show a clear difference overall between the two countries. The number of metabolic abnormalities in the US was higher than in Koreans even when abdominal obesity was not considered. The percentage of adolescents who had at least one of five MetS risk factors was $56.5\pm1.8\%$ in the US and $49.2\pm2.2\%$ in Korea.

As shown in Table 3, the prevalence of obesity as assessed by BMI in US adolescents was approximately twice that of Korean adolescents, $18.1\pm3.2\%$ (males $22.0\pm2.6\%$, females $13.9\pm4.9\%$) and $9.0\pm1.5\%$ (males $9.3\pm2.1\%$, females $8.5\pm2.0\%$), respectively. Based on population-weighted estimates, it can be calculated that 4.6 million US and 0.4 million Korean adolescents aged 12-19 yr are obese, using the respective national criterion for obesity. Since the combined frequency of overweight and obesity was 39.2% in the US and 21.0% in Korea, the US had more adolescents who were overweight and obese ($P<0.001$) while a greater percentage of Korean adolescents were normal weight.

Since there were significant differences in mean BMI levels between the two countries, we compared the frequency of the individual MetS risk factors in each of three weight cat-

Table 4. Distribution of MetS and its components by BMI levels: the US NHANES 2003-04, Korea NHANES 2005

Parameters	US			Korea		
	5th≤ <85th (normal weight)	85th≤ <95th (overweight)	95th≤ (obese)	5th≤ <85th (normal weight)	85th≤ <95th (overweight)	95th≤ (obese)
Prevalence of metabolic syndrome and its components						
MetS[§]	0.7 (0.6)	4.9 (2.5)	20.8 (6.2)	0.0 (0.0)	5.8 (2.9)	24.3 (6.4)
Abdominal obesity	7.9 (1.7)	61.3 (9.3)	87.7 (3.0)	0.2 (0.2)[‡]	26.4 (5.6)[†]	64.9 (8.5)*
Hyperglycemia	11.9 (3.2)	9.0 (4.1)	14.4 (3.8)	3.4 (0.9)*	0.0 (0.0)*	5.8 (3.3)
Hypertriglyceridemia	8.5 (2.0)	16.3 (5.5)	22.8 (4.9)	4.8 (1.1)	11.6 (3.8)	24.3 (6.7)
Low HDL-C	13.5 (1.9)	27.3 (6.3)	40.5 (7.0)	36.8 (2.6)[‡]	63.7 (6.3)[‡]	59.8 (8.6)
High BP	1.6 (0.8)	3.1 (1.9)	12.3 (5.3)	5.3 (1.4)*	7.1 (3.1)	16.2 (5.4)
Number of metabolic abnormalities						
1≤ (not considering abdominal obesity)	35.3 (4.1)	78.4 (5.9)	94.8 (2.3)	43.6 (2.7)	72.3 (5.1)	79.4 (8.8)
2≤	7.5 (1.7)	29.9 (6.7)	49.8 (8.5)	6.6 (1.3)	30.7 (6.0)	59.7 (8.2)
3≤	0.7 (0.6)	4.9 (2.5)	21.1 (6.2)	0.2 (0.2)	5.8 (2.9)	25.6 (6.4)
4≤	0.0 (0.0)	1.9 (1.8)	9.9 (4.5)	0.0 (0.0)	0.0 (0.0)	6.2 (3.7)
5	0.0 (0.0)	1.9 (1.8)	2.1 (1.9)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)

Data are % (SE). *$P<0.05$; [†]$P<0.01$; [‡]$P<0.001$ show significant differences between the US and Korea; [§]MetS, Metabolic Syndrome.
n, sample size (estimated population represented in millions).

egories, normal, overweight, and obese (Table 4). There was no significant difference between the two countries in the frequency in which a specific number of abnormalities appeared at a given weight category. Importantly, the frequencies of MetS in US and Korean obese adolescents were 20.8 ±6.2% and 24.3±6.4%, respectively. The prevalence of MetS in the obese groups was more than 20 times that of the normal weight groups, and about four times higher than the overweight groups in both countries. The frequency of abdominal obesity in the US was significantly higher than in Korea in all three weight categories (overall $P<0.05$). The frequencies of hyperglycemia and a low HDL-C level did not show a difference overall between the two countries, but there was more than twice the prevalence of hyperglycemia (both, $P<0.05$) in the US and low HDL-C level (both, $P<0.001$) in Korea in the normal and overweight groups. Thirty-seven percent of normal weight Korean adolescents had low HDL-C levels compared to 14.0% in normal weight US adolescents. The frequency of high blood pressure was significantly higher in normal weight Korean adolescents than in US normal weight adolescents ($P<0.05$). The frequency of hypertriglyceridemia did not differ between the two countries in all weight categories.

DISCUSSION

To our knowledge, this is the first study to apply the new IDF pediatric definitions of MetS to Korean adolescents. In this study, the prevalences of MetS and obesity in US adolescents were 5.5% and 18.1%, respectively, which were approximately double the corresponding prevalences (2.5% and 9.0%) in Korean adolescents, confirming our first hypothesis. Despite lifestyle changes such as an increase in energy intake and a decrease in physical activity due to rapid economic development and the introduction of western culture in Korea, the MetS and obesity in US adolescents is still a greater problem than in Korean adolescents. Our study cannot assert that race itself confers an additional risk beyond cultural and environmental factors; therefore, a comprehensive comparison investigating the relative contribution of genetic, cultural, and environmental factors is needed.

The overall prevalence of abdominal obesity in US adolescents in our study was over four times higher (34.7%) than that of Koreans (8.4%); however, the abdominal obesity prevalence in US and Korean obese adolescents was much closer (87.7% vs. 64.9%, respectively). In both countries, the abdominal obesity prevalence was also found to be the most common of the MetS criteria in adolescents in the highest BMI category. Therefore, obese adolescents with abdominal obesity should be an important target for intervention in both countries.

The difference between the prevalence of abdominal obesity in US and Korean females was much greater than in males. Although the differences were not as marked, the opposite trend was seen when assessing obesity by BMI criterion as a larger difference existed between US and Korean males than females. This dichotomy is not easy to explain. Although fat and muscle mass distribution vary according to pubertal status and gender, neither the US NHANES nor KNHANES assessed pubertal status. Possible explanations are a gender-variable genetic predisposition to the accumulation of visceral fat which contributes to abdominal obesity or to the use of inappropriate cutoff values for abdominal and overall obesity by BMI. The visceral fat contribution to total body fat as well as pubertal status would be informative additions to future national surveys, in order that that more detailed hypotheses can be made. Current Korean growth charts include

WC while US growth charts do not. Increased awareness of the dangers of abdominal obesity could be facilitated by adding WC to the other growth charts used in the US.

The prevalence of hyperglycemia in US adolescents (11.8%) was nearly four times higher than in Koreans (3.0%), but in both countries the prevalence was the lowest for any of the components of MetS. The higher prevalence of hyperglycemia in US adolescents may be associated with their higher prevalence of obesity. It is known that Asian children have a much greater risk for type 2 diabetes at a relatively low BMI owing to their greater abdominal fat distribution compared with Caucasian children (16). However, our study showed a lower prevalence of hyperglycemia in Korea than in the US in obese adolescents. Importantly, neither NHANES nor KNHANES distinguished between type 1 and type 2 diabetes. Typically, a significant percentage of all pediatric diabetics are type 1 (17).

Hypertriglyceridemia and low HDL-C levels are often found together (18). Our study showed a higher prevalence of hypertriglyceridemia in the US but a higher prevalence of low HDL-C in Korea. Various risk factors for hypertriglyceridemia such as diabetes, obesity, alcohol intake, and a high carbohydrate diet have been reported (19). Increasing prevalences of hypertriglyceridemia and obesity in the US population during the period from 1971-2000 may be a result of a shift in consumption from a high fat to a high carbohydrate diet (20). Although little information exists to explain the low HDL-C status in Korean adolescents, we assume adult factors such as obesity, low levels of physical activity, high intakes of carbohydrate and fat, snacks, and processed foods, as well as genetics are implicated (21). Obesity is related to many types of lipid disorders (8, 22), which can help explain the higher prevalence of hypertriglyceridemia in the US overall as well as similar prevalences in the two countries among obese adolescents. Decreased levels of HDL-C in adolescents have been associated with puberty, particularly in males who experience a surge of testosterone (23). Since Tanner staging was not done in either NHANES, it is difficult to determine whether the HDL-C levels were affected by differences in pubertal development in the two countries. Higher LDL-C:HDL-C and TC:HDL-C ratios in Korean adolescents resulting from lower HDL-C and higher LDL-C of Koreans suggest that they have a more unfavorable lipid profile than their US counterparts. These results may indicate an elevated risk for CVD among this cohort of Korean adolescents. Further study is needed to understand the differences in patterns of dyslipidemia between the two countries and long-term consequences.

In our study, the overall prevalence of high blood pressure did not differ significantly between the two countries; however, US adolescents had higher pulse pressures than Korean adolescents. Elevated pulse pressure is positively associated with obesity (24); thus, higher pulse pressures in US adolescents may be related to their higher BMI relative to Korean adolescents. Anticipating a rise in the prevalences of CVD in

young adults, Healthy People 2010 emphasized the need to monitor and manage high blood pressure in adolescents (25). Some authors have suggested that high blood pressure in childhood and adolescence correlates with insulin level and insulin resistance (26) although inclusion of blood pressure as a component of pediatric MetS is still controversial. If a measurement of insulin levels is added to the KNHANES, the relationship between insulin levels and blood pressure in the two countries can be assessed.

Consensus adolescent MetS criteria have been unavailable until recently, and thus MetS prevalence estimates vary considerably. In US adolescents aged 12-19 yr, the prevalence of MetS varied from 2.0-9.6% in recent NHANES studies (16, 20). Some studies showed that the overall prevalence of MetS in US adolescents was increasing over time (6, 27). On the contrary, Ford et al. (5) reported that the prevalence of MetS in adolescents aged 12-17 was relatively stable across a 6-yr period with 4.5% for 1999-2000, 4.4-4.5% for 2001-2002, and 3.7-3.9% for 2003-4 NHANES using the 2007 IDF definition. The prevalence of the MetS in the US was higher in our study (5.5%) than in Ford et al. (5) report possibly due to differences in the age range studied. In Korea, there were two studies reporting that the overall prevalence of MetS increased from 6.8% in the 1998 KNHANES to 9.2% in the 2001 KNHANES using the criteria used by Cook et al. (7). The prevalence of MetS in males increased from 5.7% in the 1998 KNHANES to 9.0% in the 2001 KNHANES while there was no increase in females (5.1% in 1998 and 4.9% in 2001) in the age range 10-19 yr using the NCEP-ATP III-derived definition (28). These differences should be taken into account when making comparisons with these previous studies. Likewise, caution should be used when comparing the prevalence of obesity in our study with previous reports due to the utilization of different age ranges or obesity criteria. A US report showed that the prevalence of obesity among adolescents aged 12-19 yr increased from 14.8% in 1999-2000 NHANES to 16.7% in 2001-2 NHANES and to 17.4% in 2003-4 NHANES using 2000 US Growth Charts (29). A Korean report indicates that the prevalence of obesity in the10-18 yr old population increased significantly from 5.4% in the 1998 KNHANES to 11.3% in the 2001 KNHANES using 2000 US Growth Charts (8). The Korea Centers for Disease Control and Prevention (CDC) reported that the prevalence of obesity in adolescents nearly doubled from 8.7% in 1998 to 16.0% in 2005 (30) based on 1998 Korean Growth Charts. Previous studies demonstrated the increasing prevalences of obesity in US (29) and Korean (8, 30) adolescents, and it is expected that the prevalence of obesity in both countries will continue to be high despite public health interventions. The trend in the prevalence of adolescent MetS remains controversial (5, 7, 27, 28).

We expect that if the prevalence of obesity decreases in both countries, prevalences of MetS will decrease as well. However, the risk factors for MetS and obesity are not identical, and

the mechanisms underlying the development of MetS are not fully understood. The frequencies of adolescents having at least one component of MetS in the obese, overweight, and normal weight categories were 94.8%, 78.4%, and 35.3%, respectively in the US, and 79.4%, 72.3%, and 43.6%, respectively in Korea. These findings imply that even adolescents with normal weight should not be excluded from screening for MetS.

As predicted by our second hypothesis, the most prevalent abnormality in each country was also different: abdominal obesity in the US and low HDL-C levels in Korea. Prevalences of abdominal obesity, hyperglycemia, and hypertriglyceridemia were higher in the US while the prevalence of low HDL-C was higher in Korea. Unlike obesity, systematic public health programs to combat pediatric MetS in each country have not been emphasized. Further research to gain a better understanding of the genetic and environmental factors responsible for these differences is needed, and nation-specific strategies such as school-based health examinations and lipid screening should be established.

One notable finding is that despite the higher prevalence of MetS and obesity in the US, the prevalence of MetS in obese US and Korean adolescents did not significantly differ (20.8% and 24.3%, respectively). The number of metabolic abnormalities by BMI percentiles also showed no difference between the two countries. A number of studies have reported high prevalences of MetS among obese adolescents in the US (12.4-44.2%) (2, 7, 27) and Korea (33.3-64.3%) (8). In agreement with our findings, these studies also reported that the prevalence of MetS in obese adolescents did not largely differ between the two countries although Koreans had a lower BMI and obesity prevalence overall. These results imply that obese adolescents have a similar risk of MetS regardless of nationality and that the ethnic specific cut-points used in this study for the MetS criteria appropriately identified the risk of MetS across multiple ethnicities.

Our study had some limitations. First, we cannot identify the extent by which country-specific cut-off points for obesity and abdominal obesity affect the prevalence of MetS in each country. Second, while both surveys used similar anthropometric and laboratory methods, each survey used its own reference laboratories to analyze the samples and instruments, which may contribute to differences in results between countries. Third, only subjects who had fasted at least 8 hr prior to the blood collection were included in the study. Fourth, participants were excluded if any of the five components of MetS were not measured, which limited our sample size. Finally, Tanner staging was not available which could confound the results, particularly in younger adolescents.

In summary, our study compared MetS and its components in US and Korean adolescents using the 2007 IDF definition, the first international pediatric criteria. As we hypothesized, US adolescents had nearly twice the prevalence of both MetS and obesity. There were also differences in the prevalence of individual abnormalities and the most prevalent abnormality in each country. The prevalence of MetS in both countries was similar among obese adolescents, a finding that suggests that obese adolescents, regardless of ethnicity, have a similar risk for MetS and that ethnic-specific criteria for defining MetS, such as the IDF definition, may be most appropriate. Early-screening and focused interventions for MetS and obesity should be priorities in public health planning in both countries. Concomitantly, further research should be undertaken to investigate the various genetic, cultural, and environmental factors underlying the differences between the two countries.

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