Original article

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Cardiometabolic risk factors and metabolic syndrome based on severity of obesity in Korean children and adolescents: data from the Korea National Health and Nutrition Examination Survey 2007–2018

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Purpose: Data regarding cardiometabolic risk factors (CMRFs) and metabolic syndrome (MetS) by body mass index (BMI) category in Korean youth are sparse.
Methods: Among the participants of the Korea National Health and Nutrition Examination Survey 2007–2018, 9,984 youth aged 10–18 years were included in the study. Participants were classified into 4 groups based on BMI status: normal weight, overweight, class I, and class II/III obesity. CMRF prevalence, including total cholesterol, high-density lipoprotein cholesterol, low-density lipoprotein cholesterol, triglycerides, blood pressure, fasting glucose, glycated hemoglobin, and MetS, were determined using the International Diabetes Federation (IDF) and modified National Cholesterol Education Program-Adult Treatment Panel (NCEP-ATP) III criteria based on BMI category.
Results: The prevalence of overweight, class I, class II, and class III obesity was 9.52%, 7.73%, 2.10%, and 0.32%, respectively. Mean CMRF values increased with BMI, except high-density lipoprotein cholesterol. Age- and sex-adjusted odds ratios (ORs) for prediction of CMRFs also increased with BMI. Adjusted ORs for MetS among overweight, class I, and class II/II obesity were 54.2, 283.3, and 950.3 for IDF criteria and 9.56, 37.9, and 126.8 for NCEP-ATP III criteria, respectively (all $P<0.001$).
Conclusion: Class II and III obesity in Korean children and adolescents was associated with significantly increased CMRF and MetS prevalence. Therefore, it can be useful to measure CMRFs in obese children and adolescents. Further studies are required to establish screening guidelines based on obesity severity.

Keywords: Class I obesity, Class II/III obesity, Child, Adolescents, Metabolic syndrome, Cardiometabolic risk factors

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Highlights

- Obesity could be categorized as class I, II and III according to body mass index.
- Values of cardiometabolic risk factors worsened with BMI increase.
- Class II and III obesity in Korean youth was associated with an increased prevalence of cardiometabolic risk factors and metabolic syndrome.

Introduction

The prevalence of obesity and metabolic syndrome (MetS) among children and adolescents is increasing, both in Korea and worldwide.[1-5] According to the Korea National Health and Nutrition Examination Survey (KNHANES) data, in children and adolescents 10–19 years

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of age, the prevalence of overweight and obesity in 1998, 2001, and 2005 was 16.4%, 23.8%, and 24.2%, respectively.[2,4,6] As the prevalence of obesity has increased, the degree of obesity has been classified in greater detail using several criteria. According to recent guidelines, class I obesity in children and adolescents is defined as a body mass index (BMI; weight [kg] divided by height squared [m^2]) ≥95th percentile; class II/III obesity is defined as a BMI ≥120% of the 95th percentile for age and sex.[7-10]

MetS is defined as a combination of cardiometabolic risk factors (CMRFs) including abnormal waist circumference (WC), blood pressure (BP), triglycerides level, high-density lipoprotein cholesterol (HDL-C) level, and glucose level.[11] MetS increases among individuals with obesity; it is a well-known risk factor for cardiovascular disease, type 2 diabetes mellitus, and hypertension in both children and adults.[12-14] Despite the clinical importance of MetS, uniform consensus cutoff values for MetS components in children and adolescents have not been established. Thus, there are differences in the markers and cutoff values based on set of criteria.[15]

In several studies, associations with various CMRFs were reported to increase with increasing obesity severity.[4,8,9,16] Although few studies of Korean children and adolescents have been conducted, the data are outdated and do not reflect the latest criteria. Furthermore, there are sparse data regarding the prevalence of MetS based on degree of obesity.[17] Therefore, in this study, data on CMRF and MetS prevalence based on obesity severity in Korean children and adolescents were analyzed using the latest updated criteria of nationally representative data. Additionally, associations with the prevalence of various CMRFs were examined based on obesity severity.

Materials and methods

1. Study participants

Data used in this study were obtained from the fourth to seventh waves of the KNHANES performed between 2007 and 2018. The KNHANES is a cross-sectional survey that involves nationally representative data collection; it has been conducted since 1998 by the Korea Centers for Disease Control and Prevention. The KNHANES was designed using a stratified multi-stage clustered probability sampling method among non-institutionalized citizens in Korea. The KNHANES consists of a health interview, nutrition survey, and health examination. Detailed methods for KNHANES data collection are described elsewhere.[18]

Among the 97,662 individuals enrolled in the KNHANES during 2007–2018, 9,984 (5,305 boys and 4,709 girls) 10–18 years of age with anthropometric data including height, weight, and BMI were considered as candidates for analysis. The participants analyzed in the study are described in Table 1. Participants with no values for total cholesterol (TC), HDL-C, low-density lipoprotein cholesterol (LDL-C), triglycerides, or fasting glucose were excluded. Participants who fasted <8 hours were also excluded. The non-HDL-C level was calculated as the HDL-C level subtracted from the TC level (non-HDL-C = TC–HDL-C). Participants with no values for BP or glycated hemoglobin (HbA1c) were excluded, as were participants with no values for any component of MetS.

Table 1. Numbers of participants and definitions of abnormal values of CMRFs and MetS

Risk factor/MetS	No. of participants	Estimated population	Definition of abnormal values
TC	8,549	4,619,487	≥200 mg/dL
HDL-C	8,547	4,618,460	<40 mg/dL
LDL-C	8,547	4,618,460	≥130 mg/dL
Triglycerides	8,549	4,619,487	≥150 mg/dL
Non-HDL-C	8,547	4,618,460	≥145 mg/dL
BP	9,984	5,405,947	≥95th percentile for age, sex, and height
Fasting glucose	8,517	4,603,581	≥100 mg/dL
HbA1c	5,176	3,094,739	≥5.7%
MetS (IDF)	8,488	4,588,105	Central obesity plus ≥2 of 4 other criteria WC ≥90th percentile for age and sex Triglycerides ≥150 mg/dL HDL-C <40 mg/dL (boys 10–18 years of age and girls 10–15 years of age) or <50 mg/dL (girls ≥16 years of age) Systolic BP ≥130 mmHg or diastolic BP ≥85 mmHg Fasting glucose ≥100 mg/dL
MetS (modified NCEP-ATP III)	8,488	4,588,105	≥3 of 5 criteria WC ≥90th percentile for age and sex Triglycerides ≥110 mg/dL HDL-C <40 mg/dL BP ≥90th percentile for age, sex, and height Fasting glucose ≥110 mg/dL

CMRFs, cardiometabolic risk factors; MetS, metabolic syndrome; TC, total cholesterol; HDL-C, high-density lipoprotein cholesterol; LDL-C, low-density lipoprotein cholesterol; WC, waist circumference; BP, blood pressure; HbA1c, glycated hemoglobin; IDF, International Diabetes Federation; NCEP-ATP III, National Cholesterol Education Program-Adult Treatment Panel III.

2. Anthropometric measurements

Anthropometric measurements, including height, weight, and WC, were performed by trained medical personnel. Height was measured to the nearest 0.1 cm using a stadiometer (Seca 225; Seca, Hamburg, Germany). Weight was measured to the nearest 0.1 kg using an electronic balance (GL-6000-20; G-tech, Seoul, Korea). BMI was calculated as weight (kg) divided by height squared (m^2). Height, weight, and BMI were transformed to percentile values using the 2017 Korean National Growth Chart.[19] WC was measured using a flexible tape to the nearest 0.1 cm at the midpoint between the lowermost margin of the rib and the uppermost margin of the iliac crest during the expiratory phase of respiration (Seca 220; Seca). BP was measured three times on the right arm using a mercury sphygmomanometer with a cuff appropriate for arm circumference after the participant had rested for at least 5 minutes in a sitting position (Baumanometer Desk model 0320 in 2007–2012 and Baumanometer Wall Unit 33 [0850] in 2013–2018; W.A. Baum, Copiague, NY, USA). The mean values of the second and third systolic and diastolic BP measurements were used for analyses in this study.

3. Laboratory tests

Blood samples were collected by trained medical personnel. Fasting blood samples obtained from venipuncture were transported to the Central Laboratory for analysis within 24 hours. Plasma glucose, TC, HDL-C, LDL-C, and triglycerides levels were measured using a Hitachi Automatic Analyzer 7600 (Hitachi, Tokyo, Japan). HbA1c level was measured via high-performance liquid chromatography (HPLC-723G7, Tosoh, Tokyo, Japan), which is the method certified by the National Glycohemoglobin Standardization Program.

4. Definitions of obesity severity, CMRFs, and MetS

The degree of obesity was categorized based on BMI percentile for corresponding sex and age: normal weight as BMI <85th percentile; overweight as BMI ≥85th and <95th percentile; class I obesity as BMI ≥95th and <120% of the 95th percentile; and class II obesity as BMI ≥120% of the 95th percentile or ≥30 kg/m^2; and class III obesity as BMI ≥140% of the 95th percentile or ≥35 kg/m^2.[19,20]

The definitions of abnormal CMRF values are described in Table 1: TC ≥200 mg/dL, HDL-C <40 mg/dL, LDL-C ≥130 mg/dL, triglycerides ≥150 mg/dL, non-HDL-C ≥145 mg/dL,[21,22] systolic BP ≥95th percentile or diastolic BP ≥95th percentile for sex, age, and height,[23] fasting glucose ≥100 mg/dL, and HbA1c ≥5.7%.[24]

MetS was defined using 2 sets of criteria (Table 1). Using the International Diabetes Federation (IDF) criteria, MetS was defined as central obesity, which is a WC ≥90th percentile for age and sex with 2 or more of the following 4 criteria:

Table 2. Demographic and clinical characteristics of study participants

Variable	Total	Boys	Girls	*P*-value
No. of participants	9,984	5,289 (53.04)	4,695 (46.96)	
Estimated population	5,428,671	2,879,396	2,549,275	
Age (yr)	14.14±0.03	14.17±0.04	14.11±0.05	0.312
TC (mg/dL)	157.4±0.4	153.4±0.5	162.2±0.5	<0.001
HDL-C (mg/dL)	49.9±0.1	48.7±0.2	51.4±0.2	<0.001
LDL-C (mg/dL)	89.4±0.3	86.9±0.4	92.3±0.4	<0.001
Triglycerides (mg/dL)	75.4±0.5	73.5±0.7	77.5±0.7	<0.001
Non-HDL-C (mg/dL)	105.8±0.3	103.0±0.5	109.1±0.5	<0.001
Systolic BP (mmHg)	106.7±0.1	108.9±0.2	104.2±0.2	<0.001
Diastolic BP (mmHg)	65.8±0.1	66.3±0.2	65.3±0.2	<0.001
Glucose (mg/dL)	90.1±0.1	90.7±0.1	89.4±0.1	<0.001
HbA1c (%)	5.41±0.01	5.42±0.01	5.40±0.01	0.054
BMI category				<0.001
Normal weight	8,020 (80.33)	4,161 (79.09)	3,859 (81.74)	
Overweight	997 (9.52)	562 (9.89)	435 (9.09)	
Class I obesity	756 (7.73)	425 (7.85)	331 (7.61)	
Class II obesity	182 (2.10)	122 (2.76)	60 (1.34)	
Class III obesity	29 (0.32)	19 (0.41)	10 (0.22)	
MetS				
IDF criteria	159 (2.01)	81 (1.93)	78 (2.10)	0.650
Modified NCEP-ATP III criteria	285 (3.55)	168 (3.93)	117 (3.11)	0.086

Values are presented as mean±standard error or number (%).
TC, total cholesterol; HDL-C, high-density lipoprotein cholesterol; LDL-C, low-density lipoprotein cholesterol; BP, blood pressure; HbA1c, glycated hemoglobin; BMI, body mass index; MetS, metabolic syndrome; IDF, International Diabetes Federation; NCEP-ATP III, National Cholesterol Education Program-Adult Treatment Panel III.

Table 3. Prevalences of CMRFs and metabolic syndrome based on BMI category and sex

CMRFs	BMI category	All			Boys			Girls		
		Participants	Prevalence % (95% CI)	*P*-value	Participants	Prevalence % (95% CI)	*P*-value	Participants	Prevalence % (95% CI)	*P*-value
TC ≥ 200 mg/dL	NW	6,874	6.27 (5.65–6.95)	<0.001	3,583	4.21 (3.53–5.00)	<0.001	3,291	8.56 (7.54–9.70)	<0.001
	OW	843	10.83 (8.69–13.42)		473	12.24 (9.17–16.15)		370	9.07 (6.39–12.73)	
	Class I OB	649	14.48 (11.46–18.13)		362	10.86 (7.52–15.45)		287	18.50 (13.83–24.30)	
	Class II/III OB	183	18.66 (12.79–26.41)		121	19.54 (12.65–28.94)		62	16.69 (7.58–33.04)	
	Total	8,549	7.64 (7.00–8.33)		4,539	5.98 (5.22–6.85)		4,010	9.52 (8.53–10.62)	
HDL-C<40 mg/dL	NW	6,872	9.54 (8.72–10.43)	<0.001	3,582	11.76 (10.61–13.02)	<0.001	3,290	7.08 (6.10–8.21)	<0.001
	OW	843	19.29 (16.37–22.59)		473	25.00 (20.65–29.92)		370	12.18 (8.97–16.33)	
	Class I OB	649	26.13 (22.31–30.34		362	30.75 (25.47–36.58)		287	20.98 (16.11–26.85)	
	Class II/III OB	183	41.44 (33.54–49.81)		121	38.60 (29.35–48.75)		62	47.63 (33.68–61.97)	
	Total	8,547	12.52 (11.68–13.42)		4,538	15.36 (14.18–16.62)		4,009	9.30 (8.26–10.45)	
LDL-C≥130 mg/dL	NW	6,872	4.53 (4.00–5.12)	<0.001	3,582	3.19 (2.62–3.89)	<0.001	3,290	6.01 (5.15–7.00)	<0.001
	OW	843	10.18 (8.09–12.74)		473	10.89 (8.00–14.67)		370	9.29 (6.69–12.78)	
	Class I OB	649	12.87 (10.03–16.35)		421	9.02 (6.04–13.27)		287	17.15 (12.60–22.92)	
	Class II/III OB	183	20.32 (14.20–28.21)		62	21.59 (14.46–30.97)		62	17.55 (8.22–33.61)	
	Total	8,547	6.09 (5.52–6.72)		4,538	4.97 (4.28–5.76)		4,009	7.37 (6.49–8.36)	
Triglycerides≥150 mg/dL	NW	6,874	6.10 (5.44–6.84)	<0.001	3,583	5.82 (4.95–6.82)	<0.001	3,291	6.42 (5.53–7.45)	<0.001
	OW	843	15.48 (12.81–18.58)		473	19.00 (15.01–23.74)		370	11.10 (8.07–15.09)	
	Class I OB	649	21.20 (17.86–24.98)		362	19.16 (15.06–24.07)		287	23.48 (18.48–29.34)	
	Class II/III OB	183	27.80 (20.80–36.09)		121	28.66 (20.19–38.96)		62	25.92 (14.99–40.99)	
	Total	8,549	8.69 (7.97–9.46)		4,539	8.85 (7.88–9.92)		4,010	8.50 (7.55–9.56)	
Non-HDL-C≥145 mg/dL	NW	6,872	6.04 (5.43–6.72)	<0.001	3,582	4.45 (3.77–5.25)	<0.001	3,290	7.80 (6.80–8.91)	<0.001
	OW	843	13.92 (11.47–16.80)		473	15.93 (12.41–20.23)		370	11.42 (8.43–15.28)	
	Class I OB	649	20.42 (17.02–24.30)		421	16.70 (12.74–21.58)		287	24.56 (19.33–30.68)	
	Class II/III OB	183	26.45 (19.70–34.51)		62	26.74 (18.77–36.57)		62	25.81 (14.69–41.29)	
	Total	8,547	8.39 (7.72–9.12)		4,538	7.22 (6.40–8.14)		4,009	9.73 (8.71–10.86)	

(continued)

triglycerides ≥150 mg/dL, HDL-C <40 mg/dL (boys 10–18 years of age and girls 10–15 years of age) or <50 mg/dL (girls ≥16 years of age), systolic BP ≥130 mmHg or diastolic BP ≥85 mmHg, and/or fasting glucose ≥100 mg/dL.[25] Using the modified National Cholesterol Education Program-Adult Treatment Panel (NCEP-ATP) III criteria, MetS was defined as 3

Table 3. Prevalences of CMRFs and metabolic syndrome based on BMI category and sex (continued)

CMRFs	BMI category	All			Boys			Girls		
		Participants	Prevalence % (95% CI)	*P*-value	Participants	Prevalence % (95% CI)	*P*-value	Participants	Prevalence % (95% CI)	*P*-value
BP≥95th percentile for sex, age, and height	NW	8,020	4.88 (4.35–5.47)	<0.001	4,161	4.90 (4.19–5.73)	<0.001	3,859	4.85 (4.11–5.73)	<0.001
	OW	997	10.55 (8.35–13.25)		562	12.26 (9.14–16.25)		435	8.45 (5.83–12.09)	
	Class I OB	756	13.80 (11.20–16.87)		425	14.31 (10.87–18.62)		331	13.19 (9.44–18.14)	
	Class II/III OB	211	29.68 (23.11–37.20)		141	28.19 (20.46–37.47)		70	33.07 (21.79–46.71)	
	Total	9,984	6.71 (6.13–7.34)		5,289	7.11 (6.29–8.02)		4,695	6.26 (5.47–7.15)	
Fasting glucose ≥100 mg/dL	NW	6,847	6.81 (6.10–7.59)	<0.001	3,568	8.41 (7.36–9.60)	0.030	3,279	5.04 (4.27–5.94)	<0.001
	OW	839	9.69 (7.69–12.14)		471	11.81 (8.90–15.51)		368	7.05 (4.75–10.33)	
	Class I OB	649	12.24 (9.49–15.64)		361	12.93 (7.93–15.45)		288	11.47 (7.86–16.45)	
	Class II/III OB	182	13.66 (8.67–20.87)		121	8.98 (4.85–16.04)		61	24.06 (12.79–40.64)	
	Total	8,517	7.67 (6.98–8.42)		4,521	9.11 (8.14–10.19)		3,996	6.04 (5.23–6.95)	
HbA1c ≥5.7%	NW	4,128	15.47 (14.12–16.93)	<0.001	2,157	16.45 (14.62–18.45)	0.025	1,971	14.40 (12.65–16.33)	<0.001
	OW	495	17.26 (13.84–21.30)		276	19.64 (14.86–25.51)		219	14.44 (9.97–20.47)	
	Class I OB	429	21.66 (17.50–26.49)		234	19.79 (14.65–26.19)		195	23.62 (17.38–31.26)	
	Class II/III OB	124	32.23 (23.73–42.09)		81	28.80 (19.14–40.87)		3,843	39.56 (24.45–56.96)	
	Total	5,176	16.62 (15.33–17.98)		2,748	17.45 (15.74–19.31)		2,428	15.68 (14.03–17.48)	
MetS (IDF)	NW	6,824	0.05 (0.02–0.14)	<0.001	3,557	0 (0–0)	<0.001	3,267	0.11 (0.04–0.29)	<0.001
	OW	836	2.63 (1.51–4.56)		471	2.06 (0.75–5.49)		365	3.35 (1.80–6.14)	
	Class I OB	647	12.48 (9.89–15.63)		361	10.98 (7.98–14.93)		286	14.15 (10.09–19.50)	
	Class II/III OB	181	30.89 (23.64–39.22)		120	28.16 (19.84–38.29)		61	36.92 (23.88–52.20)	
	Total	8,488	2.01 (1.68–2.40)		4,509	1.93 (1.50–2.49)		3,979	2.10 (1.63–2.70)	
MetS (modified NCEP-ATP III)	NW	6,824	0.63 (0.44–0.88)	<0.001	3,557	0.53 (0.34–0.85)	<0.001	3,267	0.72 (0.44–1.17)	<0.001
	OW	836	5.68 (3.99–8.01)		471	6.57 (4.18–10.19)		365	4.55 (2.53–8.07)	
	Class I OB	647	18.96 (15.66–22.76)		361	19.91 (15.66–24.98)		286	17.90 (13.29–23.68)	
	Class II/III OB	181	42.70 (34.53–51.29)		120	42.31 (32.61–52.65)		61	43.55 (30.05–58.07)	
	Total	8,488	3.55 (3.01–4.06)		4,509	3.93 (3.32–4.65)		3,979	3.11 (2.51–3.86)	

CMRF, cardiometabolic risk factor; BMI, body mass index; CI, confidence interval; TC, total cholesterol; HDL-C, high-density lipoprotein cholesterol; LDL-C, low-density lipoprotein cholesterol; BP, blood pressure; HbA1c, glycated hemoglobin; MetS, metabolic syndrome; IDF, International Diabetes Federation; NCEP-ATP III, National Cholesterol Education Program-Adult Treatment Panel III; NW, normal weight; OW, overweight; OB, obesity.

or more of the 5 following criteria: WC ≥90th percentile for age and sex; triglycerides ≥110 mg/dL; HDL-C <40 mg/dL; systolic or diastolic BP ≥90th percentile for age, sex, and height; and/or fasting glucose ≥110 mg/dL.[26]

5. Statistical analyses

Statistical analyses were performed using Stata 16.1 (StataCorp LP, College Station, TX, USA). The svy commands and sample weights were used for all analyses. Results are expressed as either the weighted mean (standard error, SE) or the number of participants (weighted %). TC, HDL-C, LDL-C, triglycerides, and non-HDL-C levels were log-transformed for analyses because they exhibited skewed distributions; they are presented as the geometric mean (SE). Student t-test was used to compare continuous variables between groups. Chi-squared tests were used to compare proportions between groups. Multiple logistic regression analysis was performed to calculate the sex- and age-adjusted odds ratio (OR) with 95% confidence intervals (CIs) for possible associations between CMRFs or MetS and degree of obesity. Multiple regression analysis was performed to determine associations between the prevalence of each CMRF and degree of obesity. A 2-tailed *P*-value <0.05 was considered statistically significant.

Results

1. Demographic and clinical characteristics of study participants

Table 2 shows demographic and clinical characteristics of study participants. In total, 9,984 individuals were analyzed in this study: 5,289 (53.04%) were boys and 4,695 (46.96%) were girls. The mean values for TC, HDL-C, LDL-C, triglycerides, and non-HDL-C levels were higher in girls (*P*<0.001), while the mean values for systolic and diastolic BP, as well as fasting glucose, were higher in boys (*P*<0.001).

The proportion of participants with overweight, class I obesity, class II, or class III obesity was higher in boys than in girls (20.91% for boys and 18.26% for girls, *P*<0.001). The prevalence of MetS did not differ according to sex, irrespective of definition.

According to IDF criteria, prevalence was higher in girls than in boys (*P*=0.650); conversely, according to the modified NCEP-ATP III criteria, the prevalence was higher in boys than in girls (*P*=0.086).

The proportion of participants with class I, class II, or class III obesity showed an increasing trend between 2007 and 2018 (*P*=0.025, *P*=0.105, and *P*=0.508 in total, boys, and girls, respectively) (Supplementary Table 1).

2. Prevalence of CMRFs and MetS based on BMI category

Table 3 and Fig. 1 showed the prevalence of abnormal CMRFs and MetS by BMI category. Supplementary Table 2 shows the mean values for each CMRF based on BMI category and sex. Mean CMRF values were higher with increasing obesity severity, except for mean HDL-C, which was lower with increasing obesity severity.

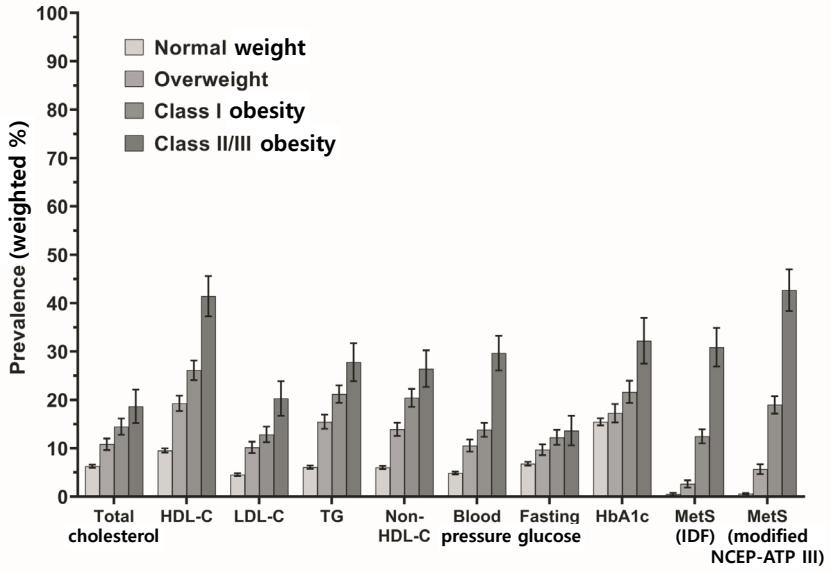

Fig. 1. Prevalences of CMRFs and MetS based on BMI category. CMRFs, cardiometabolic risk factors; BMI, body mass index; HDL-C, high-density lipoprotein cholesterol; LDL-C, low-density lipoprotein cholesterol; TG, triglycerides; HbA1c, glycated hemoglobin; MetS, metabolic syndrome; IDF, International Diabetes Federation; NCEP-ATP III, National Cholesterol Education Program-Adult Treatment Panel III.

3. Adjusted ORs for CMRFs and MetS based on BMI category

Table 4 shows adjusted ORs and 95% CIs for CMRFs and MetS based on BMI category. The ORs of high TC, low HDL-C, high LDL-C, high triglycerides, high non-HDL-C, high BP, and prevalence of MetS were greater among children and adolescents with class II/III obesity than among participants with normal weight; these factors showed tendencies to increase with increasing BMI category. Adjusted OR (95% CI) for TC for class II/III obesity in all participants was 4.11 (2.58–6.55), and adjusted OR (95% CI) for BP for class II/III obesity in all participants was 9.44 (6.53–13.66). In analyses of all participants, the OR for MetS according to IDF criteria was 950.3 (321.6–2,808.3), and the OR for MetS according to modified NCEP-ATP III criteria was 126.8 (77.9–206.5). There were few significant differences in these variables based on BMI category among girls; however, all differences were statistically significant among boys. Overweight children and adolescents had lower ORs for most CMRFs compared with

Table 4. Adjusted ORs for CMRFs and MetS based on BMI category

CMRF	BMI category	All			Boys			Girls		
		Participants	Adjusted OR (95% CI)	*P*-value	Participants	Adjusted OR (95% CI)	*P*-value	Participants	Adjusted OR (95% CI)	*P*-value
TC≥200 mg/dL	NW	6,874	(ref)		3,583	(ref)		3,291	(ref)	
	OW	843	1.85 (1.42–2.41)	<0.001	473	3.10 (2.14–4.48)	<0.001	370	1.06 (0.71–1.59)	0.759
	Class I OB	649	2.60 (1.94–3.48)	<0.001	362	2.76 (1.78–4.30)	<0.001	287	2.42 (1.66–3.53)	<0.001
	Class II/III OB	183	4.11 (2.58–6.55)	<0.001	121	6.77 (3.90–11.77)	<0.001	62	2.14 (0.86–5.34)	0.101
HDL-C<40 mg/dL	NW	6,872	(ref)		3,582	(ref)		3,290	(ref)	
	OW	843	2.25 (1.81–2.81)	<0.001	473	2.57 (1.96–3.38)	<0.001	370	1.84 (1.26–2.67)	0.001
	Class I OB	649	3.37 (2.68–4.25)	<0.001	362	3.39 (2.55–4.50)	<0.001	287	3.63 (2.51–5.24)	<0.001
	Class II/III OB	183	6.05 (4.16–8.79)	<0.001	121	4.30 (2.77–6.66)	<0.001	62	13.13 (7.18–24.03)	<0.001
LDL-C≥130 mg/dL	NW	6,872	(ref)		3,582	(ref)		3,290	(ref)	
	OW	843	2.43 (1.85–3.20)	<0.001	473	3.64 (2.47–5.37)	<0.001	370	1.59 (1.08–2.35)	0.019
	Class I OB	649	3.15 (2.31–4.29)	<0.001	421	2.99 (1.86–4.80)	<0.001	287	3.17 (2.12–4.75)	<0.001
	Class II/III OB	183	6.05 (3.83–9.54)	<0.001	62	9.52 (5.56–16.29)	<0.001	62	3.17 (1.31–7.69)	0.011
Triglycerides≥150 mg/dL	NW	6,874	(ref)		3,583	(ref)		3,291	(ref)	
	OW	843	2.81 (2.20–3.59)	<0.001	473	3.80 (2.76–5.23)	<0.001	370	1.88 (1.27–2.79)	0.002
	Class I OB	649	4.24 (3.34–5.40)	<0.001	362	3.84 (2.76–5.34)	<0.001	287	5.15 (3.65–7.26)	<0.001
	Class II/III OB	183	6.64 (4.39–10.05)	<0.001	121	6.48 (3.93–10.70)	<0.001	62	6.87 (3.31–14.25)	<0.001
Non-HDL-C≥145 mg/dL	NW	6,872	(ref)		3,582	(ref)		3,290	(ref)	
	OW	843	2.55 (2.00–3.26)	<0.001	473	4.00 (2.87–5.59)	<0.001	370	1.52 (1.06–2.18)	<0.001
	Class I OB	649	4.07 (3.17–5.22)	<0.001	362	4.29 (3.01–6.12)	<0.001	287	3.85 (2.73–5.43)	<0.001
	Class II/III OB	183	6.35 (423–9.52)	<0.001	121	8.79 (5.33–14.50)	<0.001	62	4.12 (1.99–8.49)	<0.001
BP≥95th percentile for sex, age, and height	NW	8,020	(ref)		4,161	(ref)		3,859	(ref)	
	OW	997	2.28 (1.72–3.02)	<0.001	562	2.62 (1.83–3.74)	<0.001	435	1.85 (1.18–2.88)	0.007
	Class I OB	756	3.20 (2.46–4.15)	<0.001	425	3.21 (2.25–4.59)	<0.001	331	3.16 (2.09–4.76)	<0.001
	Class II/III OB	211	9.44 (6.53–13.66)	<0.001	141	8.90 (5.59–14.19)	<0.001	70	11.05 (6.01–20.29)	<0.001

(continued)

Table 4. Adjusted ORs for CMRFs and MetS based on BMI category (continued)

CMRF	BMI category	All			Boys			Girls		
		Participants	Adjusted OR (95% CI)	*P*-value	Participants	Adjusted OR (95% CI)	*P*-value	Participants	Adjusted OR (95% CI)	*P*-value
Fasting glucose ≥100 mg/dL	NW	6,847	(ref)		3,568	(ref)		3,279	(ref)	
	OW	839	1.44 (1.10–1.89)	0.009	471	1.43 (1.01–2.02)	0.044	368	1.47 (0.94–2.30)	0.094
	Class I OB	649	1.96 (1.45–2.67)	<0.001	361	1.61 (1.07–2.41)	0.022	288	2.73 (1.74–4.28)	<0.001
	Class II/III OB	182	2.41 (1.40–4.14)	0.001	121	1.22 (0.62–2.41)	0.564	61	7.88 (3.50–17.72)	<0.001
HbA1c ≥5.7%	NW	4,128	(ref)		2,157	(ref)		1,971	(ref)	
	OW	495	1.15 (0.87–1.51)	0.318	276	1.23 (0.86–1.76)	0.258	219	1.03 (0.66–1.61)	0.889
	Class I OB	429	1.60 (1.20–2.12)	0.001	234	1.28 (0.87–1.89)	0.208	195	1.97 (1.29–3.01)	0.002
	Class II/III OB	124	2.90 (1.87–4.49)	<0.001	81	2.44 (1.40–4.27)	0.002	3843	4.14 (2.02–8.49)	<0.001
MetS (IDF)	NW	6,824	(ref)		3,557	(ref)[†]		3267	(ref)	
	OW	836	54.2 (16.9–173.9)	<0.001	471	-	-	365	32.5 (9.76–108.3)	<0.001
	Class I OB	647	283.3 (98.9–811.5)	<0.001	361	-	-	286	154.7 (51.9–461.6)	<0.001
	Class II/III OB	181	950.3 (321.6–2808.3)	<0.001	120	-	-	61	549.4 (164.0–1840.0)	<0.001
MetS (modified NCEP-ATP III)	NW	6,824	(ref)		3,557	(ref)		3267	(ref)	
	OW	836	9.56 (5.78–15.82)	<0.001	471	13.1 (6.7–25.4)	<0.001	365	6.7 (3.1–14.6)	<0.001
	Class I OB	647	37.9 (24.8–57.8)	<0.001	361	46.3 (26.7–80.2)	<0.001	286	32.1 (17.7–58.1)	<0.001
	Class II/III OB	181	126.8 (77.9–206.5)	<0.001	120	139.5 (73.9–263.5)	<0.001	61	123.7 (59.6–256.7)	<0.001

Normal weight is the reference group.
OR, odds ratio; CMRF, cardiometabolic risk factor; MetS, metabolic syndrome; BMI, body mass index; CI, confidence interval; TC, total cholesterol; HDL-C, high-density lipoprotein cholesterol; LDL-C, low-density lipoprotein cholesterol; HbA1c, glycated hemoglobin; BP, blood pressure; NW, normal weight; OW, overweight; OB, obesity.
[*]Adjusted for age and sex. [†]OR of MetS in boys could not be estimated because no participants exhibited MetS in the normal weight group.

obese participants.

Discussion

In this study, KNHANES data from 9,984 Korean children and adolescents (10–18 years of age) were analyzed to examine the associations between obesity severity and CMRFs and MetS. The prevalence of abnormal CMRFs and MetS increased with obesity severity. Notably, class II/III obesity in children and adolescents was associated with high mean values and CMRF prevalence. Additionally, the ORs for CMRFs and prevalence of MetS were higher in children and adolescents with class II/III obesity than in children and adolescents with normal weight.

Recently, several proposals have been suggested regarding the classification of obesity based on BMI. Classification of children and adolescents based on obesity severity provides a more detailed approach to patients at risk of potential complications and health problems.[27-29] According to representative KNHANES data collected from 2007–2018, the prevalence of overweight, class I obesity, and class II/III obesity was 9.52%, 7.73%, and 2.42% in children and adolescents 10–18 years of age, respectively. In the United States, the prevalence of overweight, class I obesity, and class II/III obesity was 14.8%, 11.3%, and 5.1%, respectively, in children and adolescents 2–19 years of age.[7] Although the prevalence of obesity is lower in Korea than in the United States, the prevalence in Korean children and adolescents is increasing compared with results from a Korean study conducted from 2007–2014.[17]

According to Freedman and colleagues, CMRFs (e.g., dyslipidemia, hypertension, and hyperinsulinemia) were more common in children with a BMI in the 99th percentile than in children with a BMI in the 95th percentile. In children and adolescents with a BMI in the 95th percentile (5–17 years), 70%, 39%, and 18% had at least 1, 2, or 3 CMRFs, respectively. Furthermore, in children and adolescents with a BMI in the 99th percentile (defined as severe obesity in this study), 84%,

59%, and 33% had at least 1, 2, or 3 CMRFs, respectively. In the Bogalusa cohort study, the number of CMRFs increased based on BMI percentile in children and adolescents. Among children and adolescents with a BMI in the 95th percentile according to the Centers for Disease Control growth charts, 39% had at least 2 CMRFs. Among individuals with a BMI in the 99th percentile, 59% had at least 2 CMRFs. Based on a previous study of KNHANES data analyzed between 2007 and 2014, the incidence of abnormal CMRFs was higher among individuals with more severe obesity than individuals with less severe obesity.[17] Therefore, it is important to understand the prevalence of CMRFs based on obesity severity classification. Moreover, early recognition and management of obesity based on its severity are important for preventing MetS and complications associated with obesity.

In this study, MetS prevalence differed based on a set of criteria used for obesity evaluation. Unlike adults, children and adolescents have increased insulin resistance because of physiological changes during puberty; therefore, the adult MetS definitions cannot be used for children and adolescents. Currently, there is no established uniform consensus to evaluate risk in children and adolescents.[25,30,31] However, based on these study results, according to both sets of MetS criteria, a relationship was observed between MetS and obesity severity, consistent with our CMRF findings. MetS prevalence increased with increasing obesity severity in both boys and girls.

Early onset of obesity is associated with insulin resistance and MetS in both children and adults and can lead to cardiovascular diseases during adulthood.[30,32-34] Furthermore, obesity is a well-known cause of MetS, dyslipidemia, type-2 diabetes mellitus, cardiovascular diseases, nonalcoholic fatty liver disease, and mental disorders in both children and adolescents.[4,9,27,35] Consequently, early detection and management of obesity and MetS in children and adolescents are important to prevent cardiovascular disease development in adulthood and associated health consequences.[30,31,36,37]

Although this study was conducted using a nationally representative dataset, it had several limitations. First, the sample size was small for some ages, and data for children under 10 years old were not included. Therefore, caution is needed when applying these results to younger children. Second, because of the small sample size, class III obesity (i.e., BMI ≥95th and ≥140% of the 95th percentile) could not be subdivided and analyzed. Third, while only CMRFs and MetS were investigated, other factors associated with obesity development (e.g., birth body weight, family history, physical activity, and detailed dietary habits) were not considered.[38] Therefore, the causal relationships of these associated factors could not be determined.

A study was previously performed based on data obtained from KNHANES for Korean children and adolescents between 2007 and 2014. However, the study findings are outdated, and moreover, they do not reflect the current standards for obesity and hypertension.[17] To our knowledge, this is the first study to investigate CMRF prevalence and associations with obesity in a large, nationally representative sample of Korean children and adolescents. This study is meaningful because CMRF and MetS prevalence was analyzed based on obesity severity in Korean children and adolescents using nationally representative data. This study used the most recent BMI reference data from the Korean population (published in 2018) and the latest definitions of abnormal CMRF values to present current statuses of obesity and its comorbidities. Therefore, these results could be applied to establish screening and management guidelines in clinical practice.

In conclusion, this study demonstrated the prevalence of obesity in Korean children and adolescents. The prevalence of abnormal CMRFs and MetS increased with increasing obesity severity, especially in participants with class II/III obesity. The study results indicate the importance of measuring CMRFs in obese children and adolescents, as well as the need to establish a screening guideline based on obesity severity. Furthermore, guidelines should include obesity severity within clinical criteria for effective medical screening and appropriate management of children and adolescents nationwide.

Ethical statement

Informed consent was obtained from all participants in the KNHANES. The KNHANES protocol was approved by the Institutional Review Board of the Korea Centers for Disease Control and Prevention (2007-02CON-04-P, 2008-04EXP-01-C, 2009-01CON-03-2C, 2010-02CON-21-C, 2011-02CON-06-C, 2012-01EXP-01-2C, 2013-07-CON-03-4C, and 2013-12EXP-03-5C). Since 2015, the KNHANES has not required approval by the Institutional Review Board because surveys performed by the government for public welfare in Korea have been exempt from review by an ethics committee. This study was approved by the Institutional Review Board of Seoul National University Bundang Hospital (X-2105/683-902).

Notes

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