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Outbreak of Severe Obesity and Metabolic Complications in Children and Adolescents Using the Korea National School Health Examination (KNSHE) From 2017 to 2021

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ABSTRACT

Background: This study aimed to estimate the prevalence of obesity in school children by severity and to assess the coronavirus disease 2019 (COVID-19) pandemic's impact on changes in the prevalence of obesity. In addition, the prevalence of obesity-related metabolic complications was calculated.
Methods: We used data from 390,580 school-aged children in the 2017–2021 Korea National School Health Examination to estimate the prevalence of obesity and assess secular trends in prevalence. We estimated the prevalence of metabolic complications in overweight and obese students with serological data and assessed their association with the degree of obesity, which was classified as overweight, obesity, and severe obesity per the criteria of the American Academy of Pediatrics.
Results: In 2021, the prevalence of overweight, obesity, and severe obesity among school children was 12.5%, 17.6%, and 4.9%, respectively, for boys and 10.8%, 11.9%, and 2.9%, respectively, for girls, and these values have been increasing significantly since 2017. Compared with the pre-COVID-19 period, the increase in the prevalence of obesity and severe obesity was remarkable, especially in elementary school students. The linear relationship between the prevalence of metabolic complications and the degree of obesity was evident in high school students. In elementary school students, similar relationships were found with nonalcoholic fatty liver disease and high blood pressure.
Conclusion: The severity of obesity in school-age children (especially younger children) is worsening, and this may predict an increase in the prevalence of related metabolic complications. To prevent long-term complications, it is essential to expand health screening programs.

Keywords: Metabolic Complications; Pediatric Obesity; Prevalence; Severe Obesity

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Disclosure

The authors have no potential conflicts of interest to disclose.

Author Contributions

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INTRODUCTION

A recent meta-analysis of 2,033 studies from 154 countries from 2000 to 2023 estimated the global prevalence of obesity in children and adolescents to be 8.5% (95% confidence interval [CI], 8.2–8.8), with trends in obesity prevalence worsening over the past decade (2012–2023) compared with previous periods.[1] This surge in pediatric obesity prevalence has been attributed to the COVID-19 pandemic. In the United States, the rate of increase in body mass index (BMI) among children nearly doubled, going from 0.052 per month before the pandemic to 0.100 per month midpandemic.[2] Similar observations have been made in many different countries.[3] A study conducted using data derived from the Korea National Health and Nutrition Examination Survey (KNHANES) also revealed an increase in mean BMI during the first year of the COVID-19 pandemic, particularly in children aged < 10 years.[4]

With the prevalence of obesity among young children on the rise, the World Health Organization has reported pediatric obesity as a major public health challenge of the 21st century.[5,6] A study conducted in the United States estimated that medical costs in 2019 (in dollars) were $116 more per person per year for children with obesity and $310 more per person per year for children with severe obesity than for normal weight children.[7] Pediatric obesity can lead to adult obesity and cause enormous social burden by promoting the development of metabolic complications such as type 2 diabetes mellitus (T2DM), nonalcoholic fatty liver disease (NAFLD), and dyslipidemia.[1,4,8] A shift in the average BMI to the right may indicate an increase in the severity of obesity. To understand the severity of the widespread obesity epidemic in children and adolescents, it is necessary to estimate its prevalence based on its degree.

Therefore, first, this study aimed to estimate the prevalence of obesity according to its degree (overweight/obesity/severe obesity) in children and adolescents using the Korea National School Health Examination (KNSHE) data conducted from 2017 to 2021, which is a dataset that is representative of school-aged children, to understand the trends and the COVID-19 pandemic's impact. Second, we aimed to determine the prevalence of obesity-related metabolic complications according to the degree of pediatric obesity.

METHODS

Data source and study subjects

This study was conducted using data from the KNSHE for 2017, 2018, 2019, and 2021. So far, the KNSHE has been conducted every year except for 2020, when the COVID-19 pandemic occurred, to generate basic information based on which the health status of elementary, middle, and high school students was determined. To select a representative sample of Korean students, the KNSHE used a 2-stage, stratified, cluster sampling method. Anthropometric parameters (i.e., weight and height) are measured and health surveys are conducted for all grades. Also, health screenings are conducted for first- and fourth-grade elementary school students, first year middle school students, and first year high school students. Health screening includes a visual assessment, nasal/throat/skin disease assessment, oral examination, and pathological examination. In addition, metabolic-related serological tests such as fasting glucose and total cholesterol are performed on overweight and obese students, except for first grade elementary school students.[9]

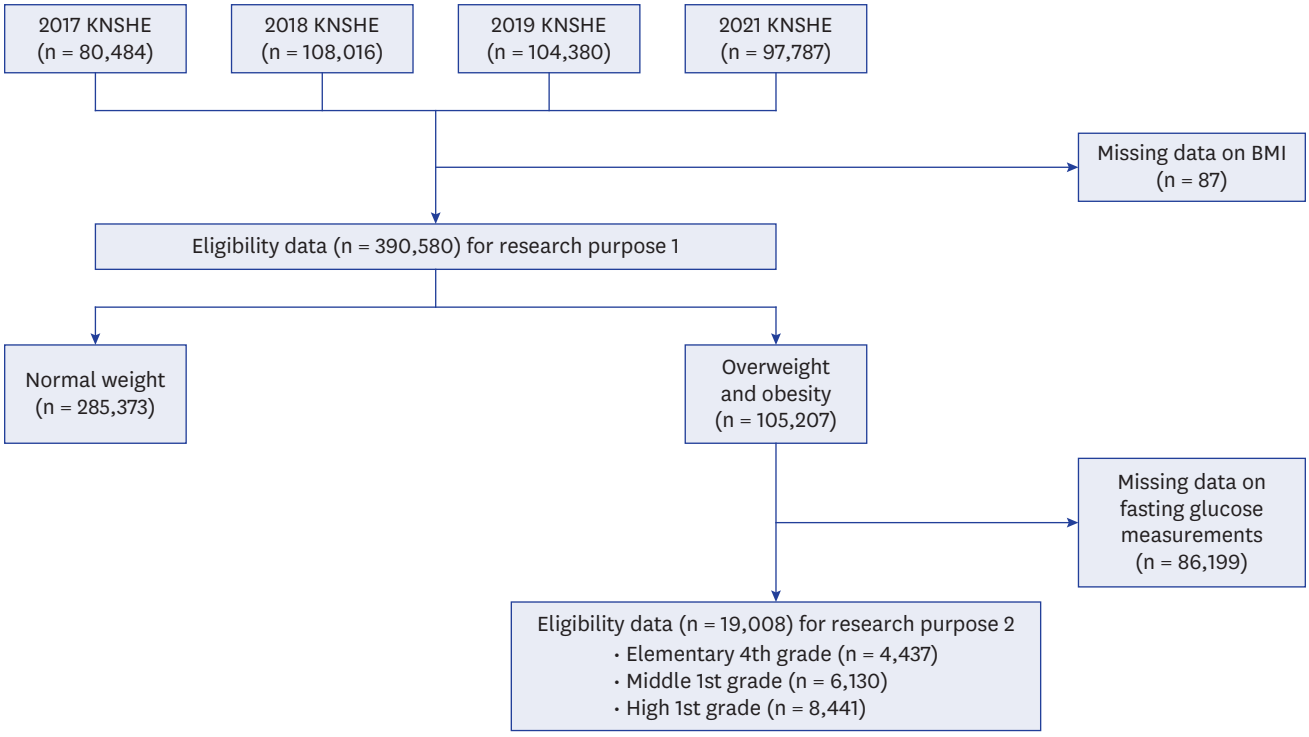


Fig. 1. Flow chart of subjects included for analysis.
KNSHE = Korea National School Health Examination, BMI = body mass index.

To assess secular trends in prevalence by degree of obesity, we included 390,580 participants, excluding 87 individuals with missing BMI data, covering the 2017–2021 period. Next, among overweight and obese students (n = 105,207), obesity-related metabolic complications were evaluated in 4,437 fourth-grade elementary school students, 6,130 first grade middle school students, and 8,441 first grade high school students with serological data. Among the serological indices, data were limited based on FBG, which had the fewest missing data entries. The flowchart of the participant inclusion process is presented in **Fig. 1**.

Definition of obesity degree and obesity-related metabolic complications

The degree of obesity was defined per the American Academy of Pediatrics criteria.[10] Based on the 2017 Korean National Growth Charts for children and adolescents,[11] normal weight was defined as a BMI less than the 85th percentile, overweight was defined as a BMI between the 85th and 95th percentile, obesity was defined as a BMI greater than or equal to the 95th percentile and less than 120% of the 95th percentile, and severe obesity was defined as a BMI greater than or equal to 120% of the 95th percentile or a BMI of at least 35.0 kg/m^2.

Blood pressure (BP) data and laboratory parameters including the levels of FBG (mg/dL), total cholesterol (mg/dL), high-density lipoprotein cholesterol (HDL-C, mg/dL), triglyceride (mg/dL), aspartate aminotransferase (U/L), and alanine aminotransferase (ALT, U/L) were recorded. Data on HDL-C and triglyceride levels were only available on the 2021 KNSHE.

Obesity-related metabolic complications included fasting hyperglycemia, diabetes mellitus, hypercholesterolemia, hypertriglyceridemia, hypo-HDL-cholesterolemia, NAFLD, and high BP. Fasting hyperglycemia was defined as an FBG of ≥ 100 mg/dL, and diabetes mellitus was defined as an FBG of ≥ 126 mg/dL. Hypercholesterolemia was defined as a total cholesterol

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level of at least 200 mg/dL, and hypertriglyceridemia was defined as a triglyceride level of at least 130 mg/dL, and hypo-HDL-cholesterolemia is defined as a serum HDL level below 40 mg/dL.[12] NAFLD was defined as having an ALT level of > 30 U/L for boys and an ALT level of > 19 U/L for girls.[13] High BP consisted of prehypertension and hypertension, as defined by clinical practice guidelines published by the American Academy of Pediatrics in 2017.[14]

Statistical analysis

All statistical analyses were conducted using SAS version 9.4 (SAS Institute Inc., Cary, NC, USA). The threshold for statistical significance was set at $P < 0.05$, utilizing a 2-tailed test.

Prevalence was estimated by school level (elementary school, middle school, and high school) and sex, taking into account differences in growth and development levels. Considering the sampling design, summary statistics were presented as weighted means with 95% CIs for quantitative data, and as the unweighted frequency with weighted percentages for categorical data. Using the data of overall students with BMI data (n = 390,580), the school level-specific prevalence and sex-specific prevalence were estimated according to obesity degree by survey year. The significance of secular trends in prevalence was assessed using a linear regression model through the PROC SURVEYREG procedure and presented as *P* for trend. Additionally, to assess differences in prevalence before and after COVID-19, we assessed the difference in prevalence between 2019 and 2021.

In addition, among overweight and obese students with serological data (n = 19,008), we estimated the school level- and sex-specific prevalence of obesity-related metabolic complications and evaluated trends in the prevalence of obesity-related metabolic complications according to the degree of obesity.

Ethics statement

The KNSHE obtained informed consent from all participants before data collection. In this study, we analyzed anonymized data provided by the KNSHE, adhering to regulations regarding the disclosure of raw data and the protection of personal identification information. The study protocol was approved by the Institutional Review Board (IRB) of Ewha Womans University Hospital (IRB No. SEUMC 2024–01–010).

RESULTS

Anthropometric characteristics of participants

Table 1 presents the mean height, weight, and BMI values of KNSHE participants by survey year. In 2017, the estimated average BMI of boys was 18.65, 21.52, and 23.02 kg/m^2 by school level from elementary school to high school. Compared with the 2017 data, the average BMI by school level in 2021 increased by 1.04, 1.18, and 0.46 kg/m^2, respectively. Meanwhile, the estimated average BMI of girls in 2017 was 17.79, 20.79, and 22.09 kg/m^2 by school level. In 2021, compared with 2017, the average BMI of elementary and middle school students increased by 0.58 and 0.19 kg/m^2, while that of high school students decreased by 0.01 kg/m^2.

Prevalence of overweight, obesity, and severe obesity and secular trends

Table 2 presents the school level- and sex-specific prevalence of overweight, obesity, and severe obesity in 2017, 2018, 2019, and 2021. Overall, from 2017 to 2021, the prevalence of overweight and obesity (BMI ≥ 85th percentile) was 26.2%, 27.6%, 28.5%, and 35.0% for

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Table 1. Anthropometric characteristics of participants from the Korea National School Health Examination by sex and school levels between 2017 and 2021

Characteristics	Boys				Girls			
	2017	2018	2019	2021	2017	2018	2019	2021
Elementary school								
No.	17,041	20,111	20,110	19,678	16,020	18,980	18,983	18,770
Age, yr	9.28 (9.25–9.3)	9.32 (9.29–9.35)	9.31 (9.28–9.34)	9.43 (9.39–9.46)	9.27 (9.25–9.29)	9.3 (9.28–9.33)	9.31 (9.28–9.34)	9.41 (9.37–9.44)
Height, cm	136.33 (136.12–136.54)	136.76 (136.56–136.95)	136.93 (136.74–137.13)	138.15 (137.89–138.4)	135.84 (135.64–136.04)	136.12 (135.91–136.33)	136.23 (135.99–136.47)	137.57 (137.3–137.84)
Weight, kg	35.53 (35.32–35.75)	36.21 (35.97–36.44)	36.4 (36.14–36.66)	38.59 (38.3–38.87)	33.59 (33.39–33.79)	33.96 (33.74–34.17)	34.14 (33.9–34.38)	35.59 (35.34–35.85)
BMI, kg/m^2	18.65 (18.57–18.74)	18.88 (18.79–18.96)	18.94 (18.84–19.03)	19.69 (19.59–19.79)	17.79 (17.71–17.87)	17.91 (17.83–17.99)	17.96 (17.88–18.04)	18.37 (18.28–18.45)
Middle school								
No.	11,229	15,455	14,936	14,252	10,508	14,695	14,229	13,993
Age, yr	13.84 (13.82–13.85)	13.87 (13.85–13.88)	13.83 (13.82–13.85)	13.87 (13.84–13.90)	13.81 (13.8–13.83)	13.85 (13.83–13.86)	13.81 (13.79–13.83)	13.86 (13.84–13.89)
Height, cm	165.54 (165.34–165.75)	165.84 (165.67–166.01)	165.85 (165.67–166.04)	166.47 (166.28–166.66)	158.68 (158.52–158.84)	158.78 (158.65–158.92)	158.87 (158.74–159.01)	159.24 (159.12–159.37)
Weight, kg	59.33 (59.02–59.64)	60.16 (59.85–60.46)	60.45 (60.12–60.79)	63.28 (62.92–63.64)	52.5 (52.24–52.77)	53.1 (52.84–53.36)	53.06 (52.78–53.34)	53.34 (53.08–53.61)
BMI, kg/m^2	21.52 (21.42–21.62)	21.73 (21.63–21.83)	21.83 (21.73–21.94)	22.7 (22.59–22.81)	20.79 (20.69–20.9)	21 (20.91–21.09)	20.96 (20.86–21.07)	20.98 (20.88–21.08)
High school								
No.	12,687	19,473	18,046	15,753	12,975	19,240	18,075	15,341
Age, yr	16.81 (16.79–16.84)	16.87 (16.85–16.88)	16.82 (16.81–16.84)	16.9 (16.87–16.93)	16.78 (16.77–16.8)	16.85 (16.83–16.86)	16.82 (16.8–16.83)	16.87 (16.83–16.91)
Height, cm	172.96 (172.79–173.12)	173.25 (173.13–173.37)	173.41 (173.29–173.54)	173.62 (173.5–173.74)	160.72 (160.59–160.85)	160.9 (160.79–161)	161.16 (160.99–161.33)	161.46 (161.35–161.58)
Weight, kg	69 (68.66–69.35)	69.61 (69.33–69.89)	70.05 (69.73–70.36)	70.93 (70.63–71.23)	57.14 (56.87–57.42)	57.09 (56.85–57.33)	57.51 (57.2–57.81)	57.63 (57.36–57.91)
BMI, kg/m^2	23.02 (22.91–23.13)	23.15 (23.06–23.23)	23.25 (23.15–23.34)	23.48 (23.39–23.58)	22.09 (21.98–22.2)	22.02 (21.93–22.11)	22.11 (21.98–22.25)	22.08 (21.97–22.18)
Total								
No.	40,957	55,039	53,092	49,683	39,503	52,915	51,287	48,104

Results are expressed as a weighted mean with 95% confidence intervals taking into account the sampling method.
BMI = body mass index.

boys and 21.7%, 22.6%, 22.9%, and 25.5% for girls. From 2017 to 2021, the prevalence of overweight, obesity, and severe obesity showed an overall increasing trend for both boys and girls (all *P* for trend < 0.001). Compared with the prevalence before COVID-19, the prevalence after COVID-19 increased for all obesity degrees regardless of school level for boys; however, for girls, the increase in prevalence was noticeable among elementary school students. All subgroups showed statistically significant increasing trend, except for girls in high school (*P* for trend = 0.126).

When the prevalence was calculated according to school level, the prevalence of obesity and severe obesity tended to increase significantly in all elementary, middle, and high schools. Compared with the pre-COVID-19 prevalence of obesity, the post-COVID-19 prevalence increased by 3.6, 2.9, and 0.7%p from elementary school to high school, respectively, and the corresponding values for severe obesity also increased by 1.0, 0.9, and 0.7%p (**Fig. 2**).

Focusing on overweight and obese children, the proportion of overweight and obesity increased by 6.4%p in 2021 from 24.0% in 2017, with the highest increase at 8.2%p in elementary schools, with increments of 7.2%p and 2.7%p in middle school and high school, respectively. Overall, the proportion of overweight children decreased while that of obese and severely obese children increased between 2017 and 2021. Compared to pre-COVID-19, the rise was even steeper: 6.1%p in elementary, 4.7 in middle, and 1.6 in high schools (**Fig. 3**).

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Table 2. Prevalence of overweight, obesity and severe obesity from the Korea National School Health Examination between by sex and school levels between 2017 and 2021

School levels	Boys					Girls				
	2017	2018	2019	2021	P_{trend}	2017	2018	2019	2021	P_{trend}
Elementary school										
Overweight	1,826 (10.75)	2,297 (11.30)	2,278 (11.36)	2,573 (13.09)*	< 0.001	1,656 (10.23)	1,959 (10.22)	2,053 (10.60)	2,236 (11.76)*	< 0.001
Obesity	2,151 (12.01)	2,624 (12.84)	2,747 (13.55)	3,547 (17.91)*	< 0.001	1,553 (8.82)	1,844 (9.7)	1,834 (9.28)	2,329 (12.1)*	< 0.001
Severe obesity	436 (2.21)	604 (2.94)	643 (3.11)	883 (4.36)*	< 0.001	232 (1.19)	276 (1.39)	309 (1.45)	430 (2.22)*	< 0.001
Subtotal	4,413 (24.97)	5,525 (27.08)	5,668 (28.02)	7,003 (35.37)	< 0.001	3,441 (20.24)	4,079 (21.31)	4,196 (21.34)	4,995 (26.09)	< 0.001
Middle school										
Overweight	1,198 (10.75)	1,685 (10.73)	1,656 (11.23)	1,883 (13.14)*	< 0.001	1,024 (9.56)	1,496 (9.97)	1,449 (10.11)	1,435 (9.96)	0.442
Obesity	1,440 (12.19)	2,076 (12.93)	2,145 (13.74)	2,634 (18.49)*	< 0.001	1,052 (9.28)	1,513 (10.21)	1,456 (9.92)	1,529 (10.84)	0.005
Severe obesity	306 (2.67)	506 (3.16)	541 (3.5)	766 (5.36)*	< 0.001	221 (1.74)	358 (2.28)	384 (2.65)	388 (2.56)	< 0.001
Subtotal	2,944 (25.60)	4,267 (26.82)	4,342 (28.46)	5,283 (36.99)	< 0.001	2,297 (20.57)	3,367 (22.46)	3,289 (22.68)	3,352 (23.36)	0.004
High school										
Overweight	1,319 (10.48)	2,074 (10.71)	1,797 (9.96)	1,745 (10.80)*	0.686	1,332 (9.97)	2,033 (10.37)	1,842 (9.95)	1,486 (9.52)	0.149
Obesity	1,785 (14.19)	2,745 (14.14)	2,686 (15.04)	2,552 (16.1)*	< 0.001	1,537 (11.55)	2,215 (11.45)	2,200 (12.14)	1,912 (12.54)	0.031
Severe obesity	505 (3.96)	818 (4.24)	813 (4.63)	863 (5.46)*	< 0.001	471 (3.43)	649 (3.24)	714 (3.97)	653 (4.46)	< 0.001
Subtotal	3,609 (28.62)	5,637 (29.09)	5,296 (29.63)	5,160 (32.36)	< 0.001	3,340 (24.95)	4,897 (25.06)	4,756 (26.07)	4,051 (26.52)	0.126
Total										
Overweight	4,343 (10.67)	6,056 (11)	5,731 (10.96)	6,201 (12.54)*	< 0.001	4,012 (10)	5,488 (10.2)	5,344 (10.32)	5,157 (10.76)	0.003
Obesity	5,376 (12.69)	7,445 (13.22)	7,578 (13.98)	8,733 (17.61)*	< 0.001	4,142 (9.72)	5,572 (10.3)	5,490 (10.17)	5,770 (11.89)*	< 0.001
Severe obesity	1,247 (2.84)	1,928 (3.36)	1,997 (3.6)	2,512 (4.89)*	< 0.001	924 (1.97)	1,283 (2.11)	1,407 (2.38)	1,471 (2.85)*	< 0.001
Subtotal	10,966 (26.20)	15,429 (27.58)	15,306 (28.55)	17,446 (35.04)	< 0.001	9,078 (21.69)	12,343 (22.61)	12,241 (22.87)	12,398 (25.50)	< 0.001

Results are expressed as an unweighted frequency with weighted percentage taking into account the sampling method.
BMI categories are based on sex- and age- specific BMI percentiles derived from the 2017 Korean Children and Adolescent National Growth Chart.
Overweight was defined as the 85th to 94th percentile, Obesity was defined as the 95th percentile or greater and less than 120% of the 95th percentile, and severe obesity was defined as 120% of the 95th percentile or greater or 35 kg/m^2 or greater.
BMI = body mass index.
*Difference in prevalence $P < 0.05$, compared to 2019.

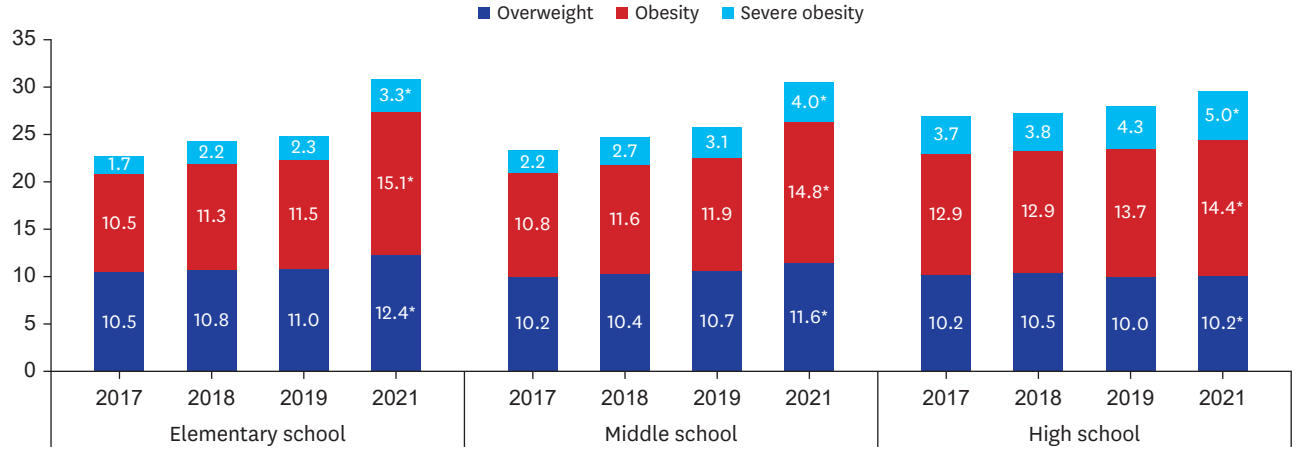


Fig. 2. Trends in prevalence of overweight, obesity and severe obesity by school levels, data from the Korea National School Health Examination.
The points indicate the weighted prevalence (%) at each school level. The horizontal axis represents the survey year. Overweight was defined as the 85th to 94th percentile, Obesity was defined as the 95th percentile or greater and less than 120% of the 95th percentile, and severe obesity was defined as 120% of the 95th percentile or greater or 35 kg/m^2 or greater.
*P for trend < 0.05.

Prevalence of metabolic complications by degree of obesity and school level

Average values of metabolic parameters related to obesity in overweight and obese children are presented together with serological data (**Supplementary Table 1**). **Supplementary Table 2** presents the school level- and sex-specific prevalence of metabolic complications according to the degree of obesity. Depending on the degree of obesity, the prevalence of fasting hyperglycemia increased from 20.4% to 30.3% ($P = 0.011$) in middle school girls, from 16.1% to 25.8% ($P < 0.001$) in high school boys, and from 12.8% to 20.7% in high school

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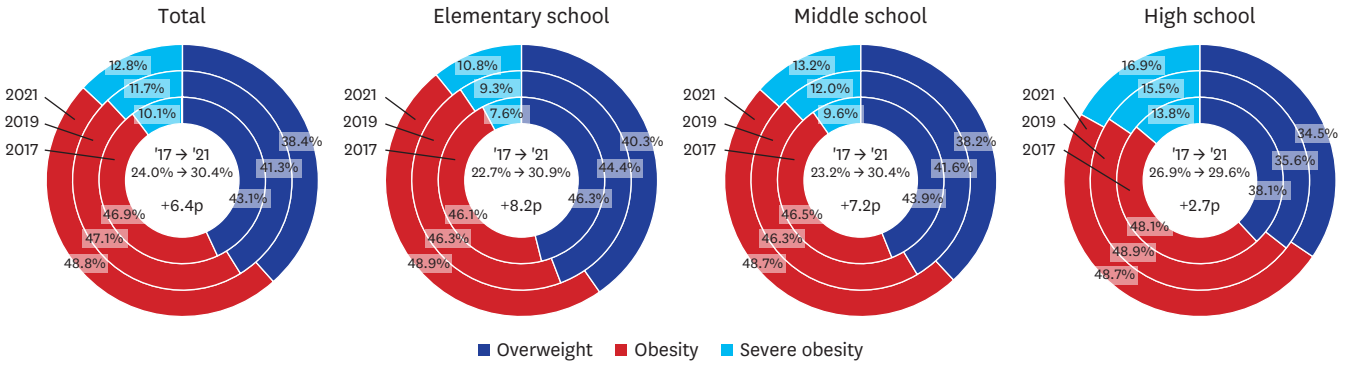


Fig. 3. Changes in proportion of overweight, obesity, and severe obesity from 2017 to 2021: data from the Korea National School Health Examination. Proportion by degree of obesity were calculated for overweight and obese children. The innermost circle represents the results from 2017, the middle circle represents the results from 2019, and the outermost circle represents the results from 2021. The values in the inner circle represent the prevalence of overweight and obesity (body mass index ≥ 85th percentile).

girls ($P = 0.001$). Similar results were obtained with hypercholesterolemia. The prevalence of hypertriglyceridemia tends to increase with the degree of obesity, especially among middle and high school students, regardless of sex. In addition, the prevalence of hypo-HDL-cholesterolemia according to the degree of obesity was particularly noticeable only in boys. The prevalence of NAFLD increased across all school levels, depending on the degree of obesity, from overweight to severe obesity. The prevalence of high BP increased with the degree of obesity, and the prevalence was high at the high school level. The prevalence of high BP among severely obese boys and girls in high school was 55.53% and 42.44%, respectively. This pattern was maintained even when evaluated by defining hypertension.

A similar pattern was demonstrated when evaluating the prevalence of obesity-related metabolic complications according to the degree of obesity by school level, regardless of sex. The prevalence of NAFLD and hypertension increased significantly depending on the degree of obesity regardless of school level, and the prevalence of DM and hypertriglyceridemia increased significantly in middle school and high school students (**Fig. 4**).

DISCUSSION

To understand the severity of the obesity epidemic among children and adolescents in Korea, this study analyzed the prevalence, associated complications, and trends according to the severity of obesity. Using representative data on Korean students, we estimated the prevalence of obesity based on its degree from 2017 to 2021 and observed an increasing trend across all obesity categories. Among school-aged children, the prevalence of overweight and obesity rose by 8.8%p in boys and 3.8%p in girls during this period, with a sharper increase observed during the COVID-19 pandemic (6.5%p in boys and 2.6%p in girls). Compared with the pre-COVID-19 period, the prevalence of obesity (boys: +3.6%p and girls: +1.7%p) and severe obesity (boys: +1.3%p and girls: +0.5%p) increased significantly in 2021, with one in three male students (35.0%) and 1 in 4 female students (25.5%) being overweight and obese. Its increase was most pronounced in elementary school children. The prevalence of metabolic complications was found to be associated with the degree of obesity, and this association was significant among high school students. Even in elementary school children, hypo-HDL-cholesterolemia, NAFLD, and high BP increased in prevalence with obesity severity, especially in boys.

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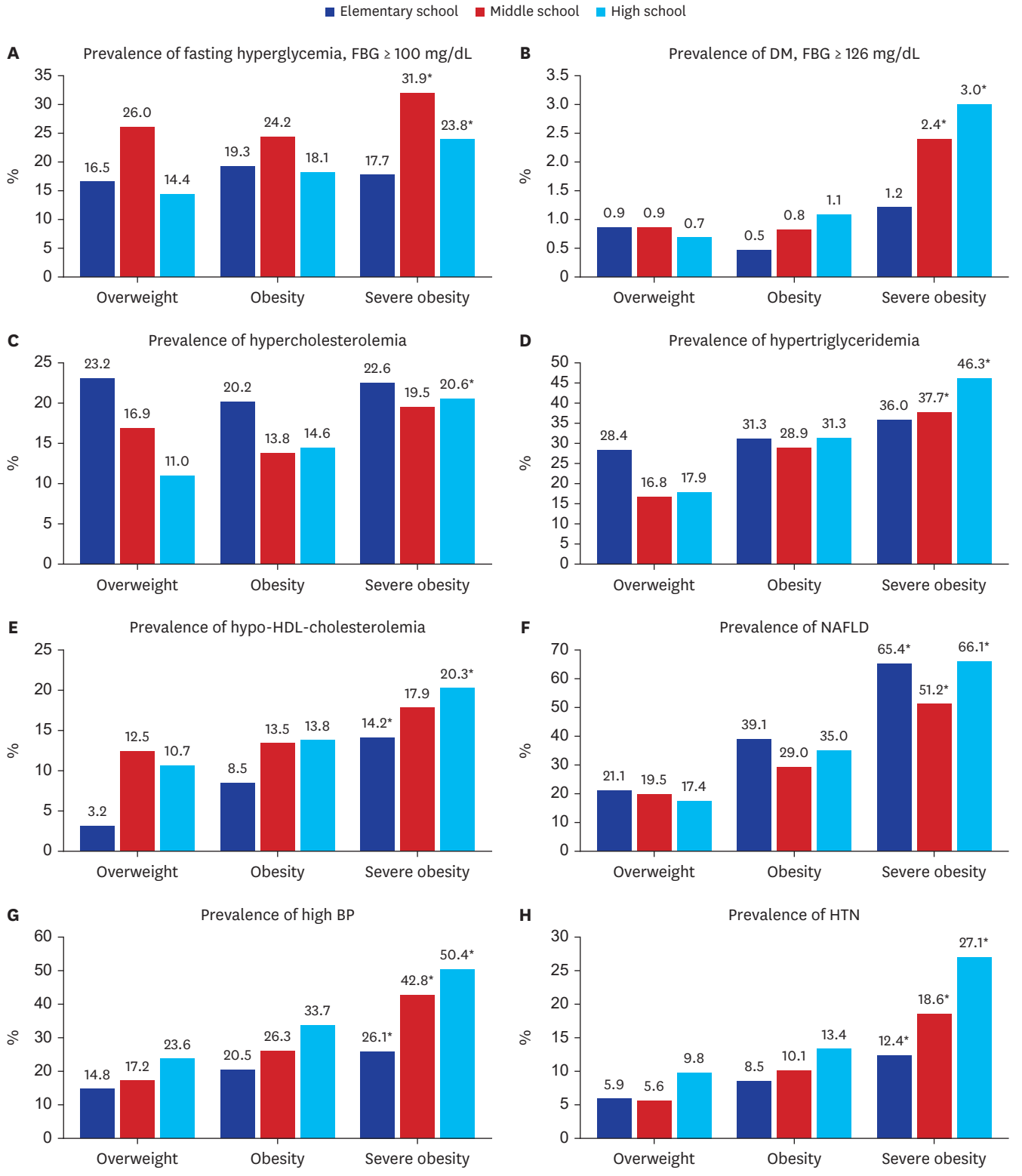


Fig. 4. Prevalence of metabolic complications in overweight and obese children by school levels and degree of obesity.
Results are expressed as weighted percentage by integrating data from 2017, 2018, 2019, and 2021 Korea National School Health Examination.
Hypertriglyceridemia and hypo-HDL-cholesterolemia were obtained using 2021 Korea National School Health Examination data.
FBG = fasting blood glucose, DM = diabetes mellitus, HDL = high-density lipoprotein, NAFLD = non-alcoholic fatty liver disease, BP = blood pressure, HTN = hypertension.
*P for trend < 0.05 across degree of obesity at each school level.

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Primary hypertension in children and adolescents can result from overweight and obesity. Our findings demonstrated a clear positive relationship with the severity of obesity, consistent with previous studies.[1,2,4] Recent findings also suggest direct causal associations between obesity and hypertension with their concurrent increasing trends.[15,16] The recent rise in the prevalence of hyperglycemia in children is predictable due to the ongoing childhood obesity epidemic.[17] Hyperglycemia and type 2 diabetes in children and adolescents are primarily attributed to beta cell dysfunction and insulin resistance, which result from childhood obesity.[18,19]

The population of obese children and adolescents continues to grow, and the rapid increase in the prevalence of obesity, especially in young children, highlights the urgency of public health measures and calls for proactive preventive interventions. As we enter the post-COVID-19 era, obesogenic behaviors and environments (e.g., increased sedentary lifestyles and delivery food consumption) have become prevalent, leading to increased weight gain and obesity prevalence in children and adolescents.[2,3] Indeed, one meta-analysis reported that the prevalence of obesity in children increased by approximately 2% during the first year of COVID-19 and that this was more pronounced in children than in adults.[3] A study conducted using KNHANES data also observed an increase in the average waist circumference in children before the age of 10 years[4] and confirmed that obesity is becoming more severe with the introduction of the pandemic era.[2,4] Accumulated evidence suggests that pediatric obesity is associated with various metabolic complications, as well as increased risks of obesity and mortality in adulthood.[4,20-22] In this study, we observed an inverse correlation between the prevalence of obesity and the age groups of our participants. As the age of onset for obesity decreases, the duration of obesity-related complications is likely to extend, thereby increasing the overall disease burden. We also need to recognize that the rise in the prevalence of severe obesity may increase this burden. Therefore, the implementation of appropriate preventive and therapeutic interventions for children is essential to minimize the burden of future health and economic consequences.

In line with previous studies,[8,23] we observed that overweight and obese school children have several metabolic complications that worsen with the severity of obesity, including hypertension, T2DM, NAFLD, and dyslipidemia. A cohort study conducted in Denmark found a 3.6% increase (baseline: 12.4%) in the prevalence of overweight and a worsening cardiometabolic risk profile in primary school children aged 6–8 years from baseline over a 20.5-month follow up period.[23] Interestingly, prospective studies assessing BMI trajectories have observed that participants who had resolved pediatric obesity had a reduced cardiometabolic risk profile in adulthood, similar to that of participants who had never been obese.[24,25] These findings highlight the feasibility of preventive and therapeutic interventions for pediatric obesity. It has also been argued that transitioning to normal weight before adolescence is critical to avoid negative health outcomes.[24]

In general, the prevalence of metabolic syndrome is known to increase as children grow, but total serum cholesterol levels may decrease with age due to physiological changes during puberty.[26] Consistent with previous studies,[26] our findings also showed higher prevalence of hypercholesterolemia and hypertriglyceridemia among elementary school students compared to middle and high school students. Therefore, in young children, a single measurement may not be sufficient to accurately assess the risk of lipid-related diseases. A more comprehensive evaluation, including family history, is necessary during school health examinations.

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Since obesity in children and adolescents can easily progress to adult obesity, early detection and preventive education are crucial. The AAP's clinical guidelines for pediatric obesity, which were published in January 2023, encouraged early intervention because obesity is a chronic disease with adverse health effects that increase over time.[10] To achieve this, identifying obesity and assessing health status must be the basis. Additionally, an evaluation of obesity-related complications may have the potential benefit of improving weight outcomes, and an evaluation of dyslipidemia with obesity is also recommended in young children aged below 10 years.[10,27] The KNSHE's health screening is conducted only for students in specific grades (1st and 4th grade of elementary school, 1st grade of middle and high school), and blood tests to check for obesity-related complications are performed only for overweight and obese students, excluding students in the first grade of elementary school.[28] Therefore, current health screening systems may miss opportunities for intervention and treatment in many obese children, and improvements are needed to overcome this.

Taking our results together with the findings of previous studies, we realize that we should not simply focus on the increasing prevalence of obesity but also see that the severity of obesity is worsening and that there should be responses at the school, district, and health care levels. School-based interventions, which are central to education, provide an ample opportunity to improve students' overall health and address obesity (e.g., providing healthier foods and promoting physical activity) in a timely manner.[28] Medical care focusing on personalized treatment requires ongoing follow up by a trained professional to monitor and correct the child's lifestyle habits through nutritional counseling, exercise counseling, and feedback provision.[27]

The main strength of our study is that it produced results using a representative data source of Korean students. As a result, our findings offer accurate estimates and valuable insights for improving student health. We also observed a clear increase in severe childhood obesity and its associated metabolic complications during the COVID-19 pandemic, which aligns with global concerns. Our producing school-based information about the obesity epidemic will help educators and policymakers determine the direction of future student health programs.

Our study has several limitations. First, as first year elementary school students were exempted from blood tests, we failed to calculate the prevalence of metabolic complications in obese students before the age of ten years. In addition, data from 2020 were not included because health screening was not conducted smoothly due to school closure caused by the COVID-19 outbreak. It is challenging to fully understand the impact of COVID-19, and the structure of the dataset has limitations in explaining causality. Finally, since fasting is difficult to implement during student health screenings,[29-31] the prevalence of metabolic complications may have been overestimated.

In conclusion, the prevalence of obesity and severe obesity among school students increased significantly in 2021 after the COVID-19 pandemic. The severity of obesity in school children is worsening, and this may enhance the early onset of metabolic complications. The significant increase in the prevalence of obesity, especially in young children, represents a public health emergency. It is essential to identify the metabolic health status of school children and expand screening for health promotion programs to prevent long-term complications and ensure prompt treatment.

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SUPPLEMENTARY MATERIALS

Supplemental Table 1

Anthropometric and biochemical data of overweight and obese children by obesity degree and school level by sex

Supplementary Table 2

Prevalence of metabolic complications in overweight and obese children by sex, school levels, and degree of obesity

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