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17-year trends of body mass index, overweight, and obesity among adolescents from 2005 to 2021, including the COVID-19 pandemic: a Korean national representative study

C.Y. BAN[1], H. SHIN[1], S. EUM[1], H. YON[1], S.W. LEE[2], Y.S. CHOI[3], Y.H. SHIN[4], J.U. SHIN[5], A. KOYANAGI[6,7], L. JACOB[6,8], L. SMITH[9], C. MIN[10], A.Ö. YENIOVA[11], S.Y. KIM[12], J. LEE[13], S.-G. YEO[14], R. KWON[10,15], M.J. KOO[10,16], G. FOND[17,18], L. BOYER[17,18], K.P. ACHARYA[19], S. KIM[20], H.G. WOO[21], S. PARK[21], J.I. SHIN[22], S.Y. RHEE[10,23], D.K. YON[3,10]

[1]Department of Medicine, Kyung Hee University College of Medicine, Seoul, South Korea
[2]Department of Precision Medicine, Sungkyunkwan University School of Medicine, Suwon, South Korea
[3]Department of Pediatrics, Kyung Hee University Medical Center, Kyung Hee University College of Medicine, Seoul, South Korea
[4]Department of Pediatrics, CHA Gangnam Medical Center, CHA University School of Medicine, Seoul, South Korea
[5]Department of Dermatology, CHA Bundang Medical Center, CHA University School of Medicine, Seongnam, South Korea
[6]Research and Development Unit, Parc Sanitari Sant Joan de Deu, CIBERSAM, ISCIII, Barcelona, Spain
[7]Catalan Institution for Research and Advanced Studies (ICREA), Pg. Lluis Companys, Barcelona, Spain
[8]Faculty of Medicine, University of Versailles Saint-Quentin-en-Yvelines, Montigny-le-Bretonneux, France
[9]Centre for Health, Performance and Wellbeing, Anglia Ruskin University, Cambridge, United Kingdom
[10]Center for Digital Health, Medical Science Research Institute, Kyung Hee University College of Medicine, Seoul, South Korea
[11]Division of Gastroenterology, Department of Internal Medicine, Tokat Gaziosmanpaşa University Faculty of Medicine, Tokat, Turkey
[12]Department of Otorhinolaryngology – Head & Neck Surgery, CHA Bundang Medical Center, CHA University School of Medicine, Seongnam, South Korea
[13]Department of Biomedical Engineering, Kyung Hee University, Yongin, South Korea
[14]Department of Otolaryngology – Head & Neck Surgery, Kyung Hee University Medical Center, Kyung Hee University College of Medicine, Seoul, South Korea
[15]Department of Biomedical Engineering, University of Michigan, Ann Arbor, Michigan, United States
[16]Department of Human Biology, University of Toronto, Toronto, Ontario, Canada
[17]AP-HM, Aix-Marseille University, CEReSS - Health Service Research and Quality of Life Center, Marseille, France
[18]FondaMental Foundation, Creteil, France
[19]Animal Quarantine Office Kathmandu, Budhanilkantha, Kathmandu, Nepal
[20]Department of Family Medicine, [21]Department of Neurology, Kyung Hee University College of Medicine, Seoul, South Korea
[22]Department of Pediatrics, Yonsei University College of Medicine, Seoul, South Korea
[23]Department of Endocrinology and Metabolism, Kyung Hee University School of Medicine, Seoul, South Korea

Abstract. – OBJECTIVE: There is a lack of pediatric studies that have analyzed trends in mean body mass index (BMI) and the prevalence of obesity and overweight over a period that includes the mid-stage of the COVID-19 pandemic. Thus, we aimed to investigate trends in BMI, overweight, and obesity among Korean adolescents from 2005 to 2021, including the COVID-19 pandemic.

SUBJECTS AND METHODS: We used data from the Korea Youth Risk Behavior Web-based Survey (KYRBS), which is nationally representative of South Korea. The study included middle- and high-school students between the ages of

Corresponding Authors: Dong Keon Yon, MD; e-mail: yonkkang@gmail.com
Jae Il Shin, MD; e-mail: SHINJI@yuhs.ac
Sang Youl Rhee, MD, Ph.D; e-mail: rheesy@khu.ac.kr

12 and 18. We examined trends in mean BMI and prevalence of obesity and/or overweight during the COVID-19 pandemic and compared these to those of pre-pandemic trends in each subgroup by gender, grade, and residential region.

RESULTS: **Data from 1,111,300 adolescents (mean age: 15.04 years) were analyzed. The estimated weighted mean BMI was 20.48 kg/m2 (95% CI, 20.46-20.51) between 2005 and 2007, and this was 21.61 kg/m2 (95% CI, 21.54-21.68) in 2021. The prevalence of overweight and obesity was 13.1% (95% CI, 12.9-13.3%) between 2005 and 2007 and 23.4% (95% CI, 22.8-24.0%) in 2021. The mean BMI and prevalence of obesity and overweight have gradually increased over the past 17 years; however, the extent of change in mean BMI and in the prevalence of obesity and overweight during the pandemic was distinctly less than before. The 17-year trends in the mean BMI, obesity, and overweight exhibited a considerable rise from 2005 to 2021; however, the slope during the COVID-19 pandemic (2020-2021) was significantly less prominent than in the pre-pandemic (2005-2019).**

CONCLUSIONS: **These findings enable us to comprehend long-term trends in the mean BMI of Korean adolescents and further emphasize the need for practical prevention measures against youth obesity and overweight.**

Key Words:
COVID-19, SARS-CoV-2, Pandemic, Adolescent, BMI, Obesity, Overweight.

Introduction

According to a World Health Organization (WHO) report[1], the number of young people who are obese has increased tenfold since 1975. Adolescent obesity is on the rise and is connected to an increase in illnesses such type 2 diabetes mellitus, hypertension, non-alcoholic fatty liver disease, obstructive sleep apnea, and dyslipidemia[2]. Severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) was first reported in Wuhan, China in December 2019[3]. The WHO declared COVID-19 a pandemic in March 2020[3,4]. Physical distancing was the most effective practice to prevent infectious diseases before the advent of vaccines[5,6]. Hence, many countries implemented school closures, the canceling of physical education classes, and public sports centers closures[7]. Several studies[7,8] reported that COVID-19 has negatively affected adolescents in terms of mental health, weight changes, and lifestyle. Moreover, according to the Centers for Disease Control and Prevention (CDC), obese adolescents are likely to experience worse COVID-19 outcomes[9]. This suggests that the prevention of adolescent obesity especially during the COVID-19 pandemic is essential from a public health perspective. Several studies[3,10] reported that mean adolescent body mass index (BMI) increased during the pandemic, but most studies[3,10] analyzed data from the early stage of the pandemic in 2020. Only one study[11], which used data up to April 2021, reflected the middle stage of the COVID-19 pandemic, but did not sufficiently explain the long-term trend of BMI.

Given this background, we extended previous studies[10] and investigated data collected from 2005 to 2021, thus encompassing the middle stage of the pandemic. The present study aimed to present long-term trends involving BMI, overweight, and obesity among Korean adolescents and provide information regarding the current state of adolescent health for policy making to prevent youth obesity, particularly during pandemic-type episodes.

Subjects and methods

Study Population and Data Sources

We utilized data from the Korea Youth Risk Behavior Web-based Survey (KYRBS), which is nationally representative of South Korea. KYRBS has been conducted since 2005 under the direction of the Korea Disease Control and Prevention Agency (KDCA) and the South Korean Ministry of Education. To provide nationally representative sampling and estimates of the total population of South Korea, the study population was chosen using two-step stratification, sample clustering, and weights. Detailed methods are published elsewhere[12,13]. The study included middle- and high-school students between the ages of 12 and 18 years, and > 95% of the participants voluntarily participated in a web-based survey administered at schools[14]. Missing data were excluded from the analysis. Data from 1,111,300 adolescents were analyzed. KYRBS data were anonymous, and the study protocol was approved by Sejong University (SJU-HR-E-2020-003) and KDCA.

Covariate Definitions

Participants' self-reported height, weight, age, and gender were used, and BMI was calculated using age- and sex-specific formulas from

the 2007 Korean national growth charts[15]. These charts separate BMI into four categories: underweight (<5th percentile), normal (5 to 84th percentile), overweight (85 to 94th percentile), and obese (≥ 95th percentile). We divided the residential areas into urban and rural[16,17]. Smoking status was defined as having smoked a cigarette within a lifetime. Parents' educational backgrounds were divided into three categories: high school or lower, college or higher, and unknown; we used a higher academic degree for either parent. We classified self-reported economic status and school performance as high, middle-high, middle, middle-low, or low[12,13].

Endpoints

This study aimed to determine whether the COVID-19 pandemic had an impact on the 17-year trend of increases in mean BMI and the prevalence of obesity and/or overweight among Korean youths from 2005 to 2021. In addition, we examined the trend change in mean BMI and prevalence of obesity and/or overweight during the COVID-19 pandemic and compared these to that of pre-pandemic trends in each subgroup by gender, grade, and residential region. We estimated β, which indicates trends for the pre-pandemic period, and β, which indicates trends during the COVID-19 pandemic. The β difference indicates whether the trend changed before or during the pandemic.

Statistical Analysis

We evaluated changes in the proportion of obese and/or overweight people stratified by gender, grade, and residence area using data from the KYRBS between 2005 and 2021. To obtain a stable estimate, the pre-COVID-19 period of the KYRBS cycle was divided into three consecutive years (2005-2007, 2008-2010, 2011-2013, 2014-2016, and 2017-2019). We conducted a weighted complex sampling analysis with binomial and linear logistic regression models, for which the results are shown as weighted odds ratios (ORs) with 95% confidence intervals (CIs) or weighted beta-coefficients with 95% CIs. We examined the KYRBS cycles as a continuous variable [2005-2007, 2008-2010, 2011-2013, 2014-2016, 2017-2019, 2020 (early pandemic), and 2021 (mid-pandemic)] in a linear regression model and as a binary variable [last pre-pandemic (2017-2019) *vs.* COVID-19 pandemic (2020-2021)] in a binary regression model[18]. SAS (v.9.4; Institute Inc., Cary, NC, USA). and SPSS (v.25.0; IBM Corp., Armonk, NY, USA) were used for all analyses[19]. We defined statistical significance as two-sided *p*-values < 0.05.

Results

The KYRBS comprised 1,111,300 adolescents in total, with 52.5% of them being male (95% CI, 51.8-53.2%) and 47.5% female (95% CI, 46.8-48.2%), between 2005 and 2021. The general properties of the weighted and crude means are presented in Table I. The weighted estimated mean age was 15.04 years (95% CI, 15.03-15.05%), with 467,703 (weighted percentage, 42.0%) of respondents in middle-school (grades 7-9th) and 644,257 (weighted percentage, 58.0%) in high-school (grades 10-12th).

The prevalence of obesity changed between 2005 and 2021 (Table II). The national weighted prevalence of obesity was 5.6% (95% CI, 5.5-5.8%) between 2005 and 2007 and was 13.5% (95% CI, 13.1-13.9%) in 2021. From 2005 to 2021, the slope for the prevalence of obesity was positive; however, before and during the pandemic, the slope of the rising trend dramatically dropped (βdiff, -0.264; 95% CI, -0.285 to -0.243). Similar trends were observed for gender, grade, and area of residence (Figure 1).

Table III shows changes in the prevalence of obesity and overweight between 2005 and 2021. The national weighted prevalence of overweight and obesity was 13.1% (95% CI, 12.9-13.3%) from 2005 to 2007 and 23.4% (95% CI, 22.8-24.0%) in 2021. Although the slope for the prevalence of overweight and obesity had been positive for 17 years, the prevalence of these conditions dramatically declined between the pre-pandemic and the pandemic periods (βdiff, -0.188; 95% CI, -0.204 to -0.172).

Table IV illustrates the national crude mean and overall 17-year trend of mean BMI in Korean adolescents from 2005 to 2021, including the COVID-19 pandemic period. Between 2005 and 2007, the estimated national weighted mean BMI was 20.48 kg/m^2 (95% CI, 20.46-20.51), and this was 21.61 kg/m^2 (95% CI, 21.54-21.68) in 2021. Even though the mean BMI gradually increased over the past 17 years, the change in mean BMI during the pandemic was noticeably less than that before the pandemic. (βdiff, -0.031; 95% CI, -0.034 to -0.028). The slope difference remained constant regardless of the participants' gender, grade, or neighborhood of residence.

Table I. Baseline of participating Korean adolescents in the KYRBS, 2005-2021 (n =1,111,300).

Characteristic	Weighted sample, weighted mean (95% CI) or weighted % (95% CI)	Crude sample, n (%) or median (IQR)
Age, years	15.04 (15.03-15.05)	15.00 (14.00-16.00)
Grade		
7th-9th grade (middle school)	40.7 (40.4-41.0)	467,703 (42.0)
10th-12th grade (high school)	59.3 (59.0-59.6)	644,257 (58.0)
Sex, male	52.5 (51.8-53.2)	573,137 (51.6)
Body mass index, kg/m^2	20.79 (20.78-20.81)	20.32 (18.51-22.64)
Body mass index, kg/m^2		
Underweight (below 5th percentile)	8.2 (8.1-8.2)	89,320 (8.0)
Normal (5th-85th percentile)	76.4 (76.2-76.5)	846,119 (76.1)
Overweight (85th-95th percentile)	8.1 (8.0-8.1)	90,941 (8.2)
Obese (above 95th percentile)	7.4 (7.4-7.5)	84,950 (7.6)
Region of residence		
Rural	54.1 (53.7-54.5)	596,112 (53.6)
Urban	45.9 (45.5-46.3)	515,218 (46.4)
Smoking	21.2 (21.0-21.4)	233,389 (21.0)
Highest educational level of parents		
High school or lower	33.8 (33.5-34.1)	389,146 (35.0)
College or higher	51.1 (50.8-51.4)	543,449 (48.9)
Unknown	15.1 (14.9-15.2)	178,735 (16.1)
Economic level		
High	8.1 (8.0-8.2)	87,875 (7.9)
Middle-high	27.0 (26.9-27.2)	292,257 (26.3)
Middle	46.7 (46.6-46.9)	523,783 (47.1)
Middle-low	14.3 (14.2-14.5)	163,259 (14.7)
Low	3.8 (3.8-3.9)	44,156 (4.0)
School performance		
High	12.2 (12.1-12.3)	135,997 (12.2)
Middle-high	25.5 (25.4-25.6)	281,898 (25.4)
Middle	28.5 (28.4-28.6)	317,293 (28.6)
Middle-low	23.4 (23.3-23.5)	259,898 (23.4)
Low	10.4 (10.3-10.5)	116,244 (10.5)

BMI, body mass index; CI, confidence interval; IQR, interquartile range; KYRBS, Korea Youth Risk Behavior Web-based Survey.

Discussion

This study conducted a long-term trend analysis utilizing nationally representative survey data of over one million South Korean adolescents (n = 1,111,300) from 2005 to 2021 and examined the 17-year trends in the prevalence of obesity and/or overweight during the early and mid-pandemic period compared to the pre-pandemic period. The 17-year trends in terms of total mean BMI exhibited a considerable rise across different gender, age groups, and geographic regions, from 20.48 kg/m^2 in 2005-2007 to 21.61 kg/m^2 in 2021. Similar patterns were observed for the prevalence of obesity. However, during the COVID-19 pandemic, the slope of the mean BMI and prevalence of obesity and/or overweight declined. Furthermore, a similar tendency was found in the analysis stratified by age, gender, and area of residence. In particular, a decrease in the slope was noticeable in female and middle-school students. Therefore, trend analysis using long-term data can correctly inform about the impact of the pandemic on adolescents' obesity risk.

Comparison with Previous Studies

Previous studies mainly focused on the short-term trends of mean BMI between pre-pandemic and during pandemic periods[3,7]. Importantly, our study was a large-scale nationally representative study that compared long-term pre-pandemic trends in BMI and the prevalence of obesity and/or overweight among adolescents with those of trends during the pandemic, which include not only the early stage but also the mid-stage of the pandemic from 2020 to 2021.

Table II. 17-year trends in obesity from 2005-2021, during the COVID-19 pandemic.

	2005-2007	2008-2010	2011-2013	2014- 2016	2017-2019	2020 (early pandemic)	2021 (mid pandemic	Before the COVID-19 pandemic, β (95% CI)[a]	After the COVID-19 pandemic, β (95% CI)[a]	Trend difference, β_{dif} (95% CI) pandemic),	2017-2019 *vs.* 2020-2021 (COVID-19 OR (95% CI)[b]
Obesity, weighted mean % (95% CI)											
Overall	5.6 (5.5-5.8)	5.3 (5.1-5.4)	6.1 (6.0-6.3)	7.8 (7.6-8.0	10.6 (10.4-10.8)	12.1 (11.7-12.5)	13.5 (13.1-13.9)	**0.353 (0.337-0.369)**	**0.089 (0.075-0.103)**	**-0.264 (-0.285--0.243)**	**1.236 (1.194-1.280)**
Sex, weighted % (95% CI)											
Male	7.1 (6.9-7.3)	6.8 (6.6-7.0)	7.4 (7.2-7.6)	9.4 (9.2-9.6)	13.1 (12.8-13.4)	15.6 (15.1-16.1)	17.5 (17.0-18.1)	**0.338 (0.320-0.357)**	**0.113 (0.098-0.129)**	**-0.225 (-0.249--0.201)**	**1.315 (1.266-1.365)**
Female	4.0 (3.8-4.2)	3.6 (3.4-3.7)	4.7 (4.6-4.9)	6.0 (5.8-6.2)	7.9 (7.7-8.1)	8.4 (7.9-8.8)	9.1 (8.7-9.6)	**0.392 (0.366-0.417)**	**0.050 (0.030-0.070)**	**-0.342 (-0.374--0.310)**	**1.117 (1.062-1.175)**
Grade, weighted % (95% CI)											
7th-9th grade (middle school)	5.2 (5.0-5.4)	4.9 (4.7-5.2)	5.7 (5.5-5.9)	6.6 (6.4-6.9)	8.8 (8.5-9.1	10.9 (10.3-11.5)	12.1 (11.5-12.7)	**0.282 (0.257-0.307)**	**0.120 (0.098-0.142)**	**-0.162 (-0.195--0.129)**	**1.346 (1.274-1.422)**
10th-12th grade (high school)	6.0 (5.8-6.3)	5.5 (5.3-5.7)	6.5 (6.3-6.6)	8.5 (8.3-8.8)	11.8 (11.5-12.0)	12.9 (12.4-13.4)	14.4 (13.8-15.0)	**0.385 (0.365-0.406)**	**0.074 (0.057-0.091)**	**-0.311 (-0.338--0.285)**	**1.184 (1.136-1.235)**
Region of residence, weighted % (95% CI)											
Rural	5.5 (5.3-5.7)	5.3 (5.0-5.5)	6.2 (6.0-6.4)	7.9 (7.6-8.1)	10.7 (10.4-11.0)	12.0 (11.4-12.5)	13.6 (13.0-14.1)	**0.370 (0.347-0.394)**	**0.087 (0.069-0.105)**	**-0.283 (-0.313--0.253)**	**1.220 (1.165-1.277)**
Urban	5.8 (5.6-6.0)	5.3 (5.1-5.5)	6.0 (5.8-6.2)	7.7 (7.5-8.0)	10.5 (10.2-10.8)	12.3 (11.7-12.9)	13.4 (12.7-14.1)	**0.330 (0.307-0.353)**	**0.092 (0.070-0.115)**	**-0.243 (-0.272--0.214)**	**1.258 (1.193-1.328)**

CI, Confidence interval; OR, odds ratio. [a]We examined the KYRBS cycles as a continuous variable [2005-2007, 2008-2010, 2011-2013, 2014-2016, 2017-2019, 2020 (early pandemic), and 2021 (mid-pandemic)] in a linear regression model. [b]We examined the KYRBS cycles as a binary vriable [last pre-pandemic (2017-2019) *vs.* COVID-19 pandemic (2020 to 2021)] in a binary regression model. **Bold** numbers indicate a statistically significant difference (p-values < 0.05).

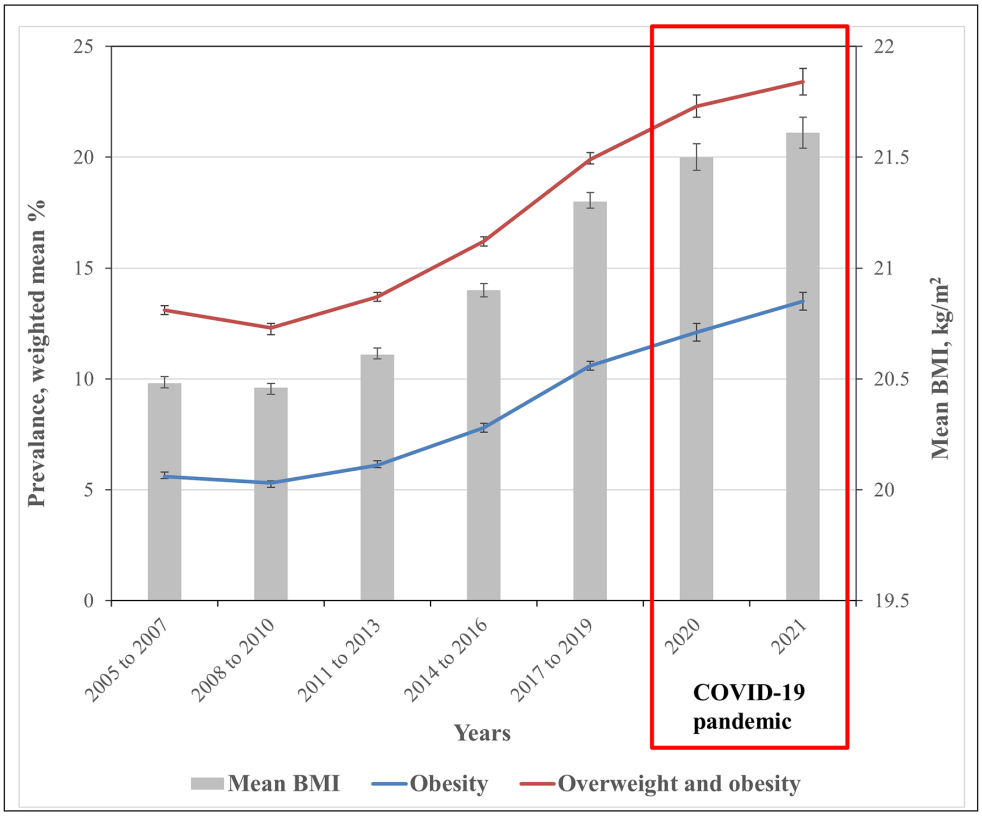

Figure 1. 17-year trends in body mass index, overweight, and obesity from 2005 to 2021 during the COVID-19 pandemic: a Korean national representative study.

Previous studies[3,7,20] concerning BMI change indicate a positive trend in weight gain in 2020 compared to pre-pandemic. These results are similar to the results of our study; however, we demonstrated that the slope was significantly decreased during the COVID-19 pandemic[21]. Certain previous studies[11] analyzed a small number of students or used biased data from students who visited pediatric endocrine clinics, whereas we used data on one million nation-wide adolescents. Although a study from China included 2021 data, it gathered data only after 2017, and these data from hospital sources might have been subject to selection bias[11].

Mechanism

The prevalence of obesity is influenced by a variety of factors, including environmental and psychological factors. Firstly, regarding environmental aspects, dietary behavior and physical activity of adolescents are known to significantly affect their weight[22]. Obesity is a result of excessive calorie intake, inactivity, and calorie-rich food consumption[23]. The majority of schools during the COVID-19 pandemic provided classes online, resulting in adolescents having fewer opportunities for physical activity and spending more time sitting[3]. A cross-sectional study identified that only 23.5% of youth participated in extracurricular sports, and 94.5% of children watched screens for 1.5 hours/day[24]. However, when comparing 2019 and 2020, Korean adolescents undertook anaerobic exercise more frequently in 2020 than they did in 2019. This increase in anaerobic exercise may have compensated for the decline in aerobic exercise during the COVID-19 pandemic[25].

For decades, dietary behavior changes, such as consuming fast food more frequently and eating more often, have been linked to adolescents' weight increase[22]. However, the dietary behavior of youth seems to have changed during the pandemic. In Korea, adolescents consumed less fast food, fruit, and sweet drinks during the pandemic due to less eating out and an increased tendency toward health-seeking behavior[25]. Although existing adolescents' lifestyles are linked to weight gain, changes in their lifestyle during the COVID-19 pandemic may partially compensate for these weight changes, which is also revealed in our results.

Table III. 17-year trends in overweight or obesity from 2005-2021 during the COVID-19 pandemic.

	2005-2007	2008-2010	2011-2013	2014- 2016	2017-2019	2020 (early pandemic)	2021 (mid pandemic	Before the COVID-19 pandemic, β (95% CI)[a]	After the COVID-19 pandemic, β (95% CI)[a]	Trend difference, β_{dif} (95% CI) pandemic),	2017-2019 *vs.* 2020-2021 (COVID-19 OR (95% CI)[b]
Obesity, weighted mean % (95% CI)											
Overall	13.1 (12.9-13.3)	12.3 (12.0-12.5)	13.7 (13.5-13.9)	16.2 (16.0-16.4)	19.9 (19.7-20.2)	22.3 (21.8-22.8)	23.4 (22.8-24.0)	**0.256 (0.244-0.268)**	**0.068 (0.057-0.079)**	**-0.188 (-0.204--0.172)**	**1.188 (1.156-1.222)**
Sex, weighted % (95% CI)											
Male	15.0 (14.7-15.3)	14.4 (14.1-14.7)	15.2 (14.9-15.5)	17.9 (17.6-18.2)	23.0 (22.7-23.4)	27.1 (26.5-27.8)	29.0 (28.-29.7)	**0.252 (0.238-0.266)**	**0.105 (0.093-0.118)**	**-0.147 (-0.166-0.128)**	**1.306 (1.267-1.346)**
Female	10.9 (10.6-11.2)	9.9 (9.6-10.1)	12.0 (11.8-12.3)	14.3 (14.0-14.6)	16.6 (16.3-16.9)	17.0 (16.4-17.7)	17.3 (16.7-17.9)	**0.268 (0.251-0.286)**	**0.017 (0.001-0.032)**	**-0.251 (-0.274--0.228)**	**1.042 (1.002-1.085)**
Grade, weighted % (95% CI)											
7th-9th grade (middle school)	12.8 (12.4-13.1)	12.1 (11.8-12.5)	13.7 (13.4-14.0)	15.0 (14.7-15.4)	17.9 (17.5-18.3)	21.4 (20.6-22.3)	22.5 (21.7-23.3)	**0.196 (0.178-0.213)**	**0.099 (0.082-0.116)**	**-0.097 (-0.121--0.073)**	**1.292 (1.238-1.350)**
10th-12th grade (high school)	13.3 (13.0-13.6)	12.4 (12.1-12.6)	13.7 (13.5-14.0)	16.9 (16.6-17.2)	21.1 (20.9-21.6)	22.8 (22.2-23.5)	24.0 (23.3-24.7)	**0.291 (0.276-0.306)**	**0.051 (0.038-0.064)**	**-0.240 (-0.260--0.220)**	**1.133 (1.096-1.171)**
Region of residence, weighted % (95% CI)											
Rural	12.7 (12.3-13.0)	12.3 (11.9-12.6)	13.7 (13.4-14.0)	16.2 (15.9-16.5)	20.1 (19.7-20.4)	22.1 (21.4-22.8)	23.3 (22.6-24.1)	**0.276 (0.259-0.292)**	**0.064 (0.050-0.078)**	**-0.212 (-0.234--0.190)**	**1.172 (1.130-1.215)**
Urban	13.5 (13.2-13.9)	12.3 (12.0-12.6)	13.7 (13.4-14.0)	16.2 (15.9-16.6)	19.8 (19.4-20.2)	22.5 (21.7-23.4)	23.5 (22.6-24.4)	**0.232 (0.216-0.248)**	**0.074 (0.056-0.091)**	**-0.158 (-0.182--0.134)**	**1.211 (1.160-1.265)**

CI, Confidence interval; OR, odds ratio. [a]We examined the KYRBS cycles as a continuous variable [2005-2007, 2008-2010, 2011-2013, 2014-2016, 2017-2019, 2020 (early pandemic), and 2021 (mid-pandemic)] in a linear regression model. [b]We examined the KYRBS cycles as a binary variable [last pre-pandemic (2017-2019) *vs.* COVID-19 pandemic (2020 to 2021)] in a binary regression model. **Bold** numbers indicate a statistically significant difference (p-values < 0.05).

Table IV. 17-year trends in mean BMI from 2005-2021 during the COVID-19 pandemic.

	2005-2007	2008-2010	2011-2013	2014- 2016	2017-2019	2020 (early pandemic)	2021 (mid pandemic	Before the COVID-19 pandemic, β (95% CI)[a]	After the COVID-19 pandemic, β (95% CI)[a]	Trend difference, β_{dif} (95% CI) pandemic),	2017-2019 *vs.* 2020-2021 (COVID-19 OR (95% CI)[b]
Obesity, weighted mean % (95% CI)											
Overall	20.48 (20.46-20.51)	20.46 (20.43-20.48)	20.61 (20.59-20.64)	20.90 (20.87-20.93)	21.30 (21.27-21.34)	21.50 (21.44-21.56)	21.61 (21.54-21.68)	**0.039 (0.037-0.041)**	**0.008 (0.006-0.010)**	**-0.031 (-0.034--0.028)**	**1.020 (1.015-1.024)**
Sex, weighted % (95% CI)											
Male	20.83 (20.80-20.87)	20.86 (20.83-20.89)	20.91 (20.88-20.94)	21.22 (21.19-21.26)	21.83 (21.79-21.87)	22.29 (22.22-22.36)	22.51 (22.45-22.58)	**0.036 (0.035-0.038)**	**0.015 (0.013-0.016)**	**-0.021 (-0.023--0.019)**	**1.038 (1.034-1.042)**
Female	20.09 (20.06-20.12)	20.00 (19.97-20.03)	20.28 (20.26-20.31)	20.55 (20.52-20.58)	20.72 (20.69-20.76)	20.64 (20.59-20.70)	20.64 (20.58-20.70)	**0.046 (0.044-0.049)**	**-0.003 (-0.006--0.001)**	**-0.049 (-0.053--0.045)**	**0.991 (0.985-0.997)**
Grade, weighted % (95% CI)											
7th-9th grade (middle school)	19.89 (19.86-19.92)	19.84 (19.81-19.88)	20.00 (19.97-20.03)	20.16 (20.13-20.19)	20.48 (20.44-20.52)	20.86 (20.78-20.94)	20.96 (20.87-21.04)	**0.028 (0.026-0.030)**	**0.013 (0.011-0.016)**	**-0.015 (-0.018--0.012)**	**1.036 (1.030-1.042)**
10th-12th grade (high school)	20.95 (20.93-20.99)	20.87 (20.84-20.91)	21.04 (21.01-21.07)	21.38 (21.35-21.41)	21.82 (21.78-21.86)	21.90 (21.82-21.98)	22.03 (21.94-22.11)	**0.044 (0.042-0.046)**	**0.005 (0.003-0.007)**	**-0.039 (-0.042--0.036)**	**1.012 (1.006-1.017)**
Region of residence, weighted % (95% CI)											
Rural	20.41 (20.37-20.45)	20.44 (20.40-20.49)	20.61 (20.57-20.64)	20.89 (20.86-20.93)	21.31 (21.26-21.35)	21.47 (21.39-21.55)	21.61 (21.53-21.70)	**0.043 (0.040-0.045)**	**0.008 (0.005-0.010)**	**-0.035 (-0.039--0.031)**	**1.019 (1.013-1.024)**
Urban	20.56 (20.52-20.60)	20.47 (20.43-20.50)	20.62 (20.58-20.66)	20.91 (20.87-20.95)	21.29 (21.24-21.34)	21.53 (21.44-21. 64)	21.61 (21.50-21.72)	**0.035 (0.032-0.037)**	**0.008 (0.005-0.011)**	**-0.027 (-0.031--0.023)**	**1.022 (1.015-1.029)**

CI, Confidence interval; OR, odds ratio. [a]We examined the KYRBS cycles as a continuous variable [2005-2007, 2008-2010, 2011-2013, 2014-2016, 2017-2019, 2020 (early pandemic), and 2021 (mid-pandemic)] in a linear regression model. [b]We examined the KYRBS cycles as a binary variable [last pre-pandemic (2017-2019) *vs.* COVID-19 pandemic (2020 to 2021)] in a binary regression model. **Bold** numbers indicate a statistically significant difference (p-values < 0.05).

Finally, with regard to psychological aspects, adolescent obesity and mental health have a bi-directional relationship. Among US teenagers, suicide-related behaviors, negative emotions, and sentiments of grief and hopelessness, increased significantly from 2009 to 2019[26]. Depression and anxiety activate the hypothalamus-pituitary-adrenal axis, increasing the release of cortisol and thereby exacerbating obesity[27]. In addition, the rate of adolescents experiencing anxiety, depression, and stress increased during the early pandemic[28]. Nonetheless, in response to the pandemic, population level resilience in mental health may be developing. The COVID-19 crisis and the ensuing lockdown limitations caused an increase in the average level of psychological anguish from March to April 2020; however, the degree of distress had returned to mid-March levels by June 2020[29]. Mental stress had increased in the early COVID-19 pandemic but may have decreased mid-pandemic. Therefore, the psychological effect of the pandemic decreased during the mid-pandemic period, which may explain why the mean BMI during the pandemic was lower than expected.

Public Health Implications

According to studies[30], adolescent obesity readily progresses to adult obesity, and adult obesity is linked to several comorbidities, such as cancer, diabetes, and cardiovascular disease. Additionally, according to the CDC, obese adolescents may experience severe COVID-19 outcomes[9]. In the event of a pandemic, ESPEN specialists recommend supplying obese patients who frequently experience key micronutrient deficiencies several supplements, including vitamins (vitamins A, B6, B12, C, D, and E and folate) and trace elements (zinc, selenium, and copper), to strengthen their immune systems[31]. The government should assist individuals in obtaining inexpensive, wholesome diets, particularly for families with low socioeconomic status backgrounds. Furthermore, the government should support local schools in extending opening hours for gyms, playgrounds, and sports fields so that adolescents can engage in more physical activity. Hospitalists and parents should routinely measure children's weight and height and plot them on growth charts to calculate BMI and assess patterns. In addition, the government should strengthen physical activity guidelines for adolescents to support and encourage them to be physically active.

Analyzing global policy, we suggest that the government should focus on adolescents' obesity issues and phasing online assessment methods as an effective monitoring method for children's growth and development. In addition, considering the hereditary nature of obesity, prevention policies should be implemented for both adolescents and parents[32].

Strengths and Limitations

The significance of this study is that it used large-scale, population-based, nationwide adolescent data to examine trends in BMI changes, particularly during the early and middle stages of the COVID-19 pandemic. It is usually difficult for researchers to obtain individual data during a pandemic, but we were able to acquire our data by using non-face-to-face methods, which were not affected by lockdowns[28]. Due of the sensitive nature of the survey's subject matter, data were collected using anonymous self-reported online questionnaires filled out in school computer labs. As a result, the long-term trends observed in this study were not biased by differences in the survey methods.

However, this study has certain limitations. First, the data were collected only from the South Korean adolescent population. Further studies are needed to confirm the impact of the COVID-19 pandemic on youth BMI in other countries. Second, because only adolescents attending school were allowed to participate, it might not be representative of all Korean youth between the ages of 12 and 18 years. However, only approximately 1.8% of those between the ages of 12 and 18 do not attend school in Korea[12,13]. Finally, since the variables of this study (e.g., weight and height) were self-reported, findings may be subject to recall and social desirability bias. To address this issue, the KYRBS should add additional survey questions, such as waist circumstance[12,13].

Conclusions

This study, which included data from the early and middle stages of the COVID-19 pandemic, was a large-scale, nationally representative study examining long-term trends in BMI and the prevalence of obesity and overweight among one million adolescents. Trends in mean BMI, obesity, and overweight showed a considerable rise from 2005 to 2021; however, the rise during the COVID-19 pandemic (2020-2021) was less than expected given the regression before the pandemic (2005-2019). Our findings help comprehend the long-term trends in Korean adolescents' BMI and echo the need for effective preventive measures

to reduce obesity. This study urges follow-up research to examine how specific variables changed before and after the epidemic to pinpoint the causal variables that affect adolescent obesity.

Informed Consent
All participants provided written informed consent.

Ethics Approval
The KYRBS data were anonymous, and the study protocol was approved by the Korean Centers for Disease Control and Prevention Agency (KCDA) and Institutional Review Board of Sejong University (SJU-HR-E-2020-003).

Conflicts of Interest
The authors declare no conflict of interest. No financial or non-financial benefits have been received or will be received from any party related directly or indirectly to the subject of this article.

Data Availability Statement
Data are available on reasonable request. Study protocol, statistical code: available from DKY (e-mail: yonkkang@gmail.com). Data set: available from the Korean Centers for Disease Control and Prevention Agency (KCDA) through a data use agreement.

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Authors' Contributions
Dr. Dong Keon Yon had full access to all data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis. All authors have approved the final version of the manuscript before submission. Study concept and design: CYB and DKY; Acquisition, analysis, or interpretation of data: CYB and DKY; Drafting of the manuscript: CYB and DKY; Critical revision of the manuscript for important intellectual content: Chae Yeon Ban, Hyoin Shin, Seounghyun Eum, Hyunju Yon, Seung Won Lee, Yong Sung Choi, Youn Ho Shin, Jung U Shin, Ai Koyanagi, Louis Jacob, Lee Smith, Chanyang Min, Abdullah Özgür Yeniova, So Young Kim, Jinseok Lee, Seung-Geun Yeo, Rosie Kwon, Min Ji Koo, Guillaume Fond, Laurent Boyer, Krishna Prasad Acharya, Sunyoung Kim, Ho Geol Woo, Sangil Park, Jae Il Shin, Sang Youl Rhee, Dong Keon Yon; Statistical analysis: CYB and DKY; Study supervision: DKY, JIS, and SYR. DKY supervised the study and is guarantor for this study. The corresponding author attests that all listed authors meet the authorship criteria and that no others meeting the criteria have been omitted.

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