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Secular trends in dental caries in Korean children and adolescents: 2007–2019 Korea National Health and Nutritional Examination Survey

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Dental caries is a common preventable childhood disease that has negative effects on physical, psychological, and social well-being. The present study was conducted to examine the secular trends in the prevalence of dental caries among Korean children and adolescents over time through subgroup analysis based on age, sex, abdominal obesity, obesity, and metabolic syndrome (MetS). This serial cross-sectional study utilized representative data from the Korea National Health and Nutritional Examination Survey, covering the period from 2007 to 2019. The study participants included 9,702 children and adolescents aged between 10 and 18 years. A linear-by-linear association test was performed to evaluate the secular trend of dental caries according to the subgroups. The mean prevalence of dental caries significantly decreased in both boys and girls during the study period (all p-values for trend < 0.001). These trends were consistent across different age subgroups: 10–12, 13–15, and 16–18 years. In subgroup analysis, the prevalence of dental caries significantly decreased in normal-weight boys and girls (all p-values for trend < 0.001). However, no significant decrease was observed in the overweight or obese groups for either sex. Importantly, the prevalence of dental caries did not decrease significantly in subgroups with abdominal obesity or MetS. In the non-abdominal obesity group, both boys and girls showed a significant decrease in dental caries prevalence (all p-values for trend < 0.001), while in the abdominal obesity group, a significant decrease was observed only in boys (p-value for trend = 0.027). No significant decrease was observed in the abdominal obesity group for girls. Similarly, in the non-MetS group, both boys and girls showed a significant decrease in dental caries prevalence (all p-values for trend < 0.001), while no significant decrease was observed in the MetS group for both sexes. The prevalence of dental caries has significantly decreased over the past 13 years among Korean children and adolescents. However, in subgroups with obesity or overweight, abdominal obesity, and MetS, no decrease was observed in the prevalence of dental caries.

Keywords Dental caries, Children, Adolescent, Obesity, Abdominal obesity, Metabolic syndrome

According to the 2017 Global Burden of Disease Study, oral diseases affected approximately 3.5 billion individuals, with untreated dental caries being one of the most prevalent non-communicable diseases[1]. Dental caries, a common childhood ailment, has negative consequences such as tooth loss, impaired chewing function, poor nutrition, low self-esteem, reduced quality of life, and broader impacts on global health[2]. Recognizing the global burden of dental caries, various public health measures have been implemented to mitigate its prevalence, including oral health education, community water fluoridation, fluoride varnish application, dental sealants, antibacterial rinses, and dietary interventions[3,4].

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The collective efforts have led to a notable decline in the global prevalence of dental caries. A previous study that analyzed 46 countries from the 1990s to 2010s reported a global trend of decreasing dental caries, not only in high-income countries but also in middle- and low-income countries[5]. In the U.S. pediatric population, there has been a decrease in the prevalence of dental caries over the past 10 years, from 2011 to 2020[6]. Recent trends in dental caries among children and adolescents in Taiwan and Korea also demonstrate a similar pattern[4,7]. However, not all populations have experienced a decline in dental caries prevalence. Recent findings by Hao et al. reported an increase in dental caries prevalence among Chinese students from 2010 to 2019, rising from 39.75–53.21%[8]. Interestingly, their study found that underweight children and adolescents had the highest prevalence of dental caries (62.82%), while children and adolescents with higher BMI levels tended to have lower caries prevalence. This suggests that nutritional status, metabolic health, and systemic conditions play a significant role in dental caries susceptibility.

One emerging factor influencing dental caries prevalence is the association with metabolic abnormalities, including obesity and metabolic syndrome (MetS). Several studies have reported a potential link between increased dental caries and childhood obesity, with dietary habits, frequent sugar intake, and metabolic dysregulation playing critical roles[8,9]. According to the World Health Organization's (WHO) 2016 report, over 340 million children and adolescents aged 5–19 were identified as overweight or obese[10]. A rising trend in metabolic abnormalities, such as type 2 diabetes, obesity, dyslipidemia, and hypertension, among children and adolescents globally, including the United States, Europe, and Japan[11]. Similarly, in Korea, there has been an increase in the prevalence of obesity, abdominal obesity, and MetS among children and adolescents[12,13].

Despite growing evidence of the complex interplay between metabolic health and dental caries, the underlying mechanisms remain poorly understood, and research examining these associations across different pediatric subgroups remains limited. Given the rising prevalence of obesity and metabolic disorders among children and adolescents, it is crucial to investigate whether metabolic health influences long-term trends in dental caries prevalence.

Therefore, the present study aims to investigate the secular trends in the prevalence of dental caries among Korean children and adolescents from 2007 to 2019, stratified by sex and age subgroups. Additionally, we seek to explore trends in dental caries prevalence among subgroups with obesity, abdominal obesity, and MetS, providing novel insights into how metabolic health influences oral disease trends in the pediatric population.

Results

Characteristics of the study population

A total of 5,147 boys and 4,555 girls participated in this study, with a mean age of 14.1 ± 2.6 years for both sexes, as shown in Tables 1 and 2. Over a period of 13 years (2007 to 2019), the mean BMI for boys was 21.1 ± 4.0 kg/m^2, and their mean WC was 72.2 ± 10.9 cm. For girls, the mean BMI was 20.3 ± 3.5 kg/m^2, and their mean WC was 67.4 ± 8.6 cm. The prevalence of MetS in boys was 3.1%, while in girls, it was 1.2%. Regarding dental hygiene practices, 32.5% of boys and 49.8% of girls reported brushing their teeth more than three times daily. Additionally, 48.4% of boys and 50.3% of girls stated that they brushed their teeth before going to bed. The prevalence of dental caries among boys and girls was 60.8% and 68.4%, respectively.

Trends in the mean prevalence of dental caries over 13 years

Figure 1 illustrates the trends in the prevalence of dental caries from 2007 to 2019. The mean prevalence of dental caries in boys showed a significant decline from 68.4 to 50.0% (p for trend < 0.001). Similarly, the prevalence in girls also significantly decreased from 72.1 to 55.9% (p for trend < 0.001).

Figure 2 presents the trends in the prevalence of dental caries according to sex and age groups. The participants were classified into three age groups: 10–12, 13–15, and 16–18 years. When considering boys and girls together, the mean prevalence of dental caries significantly decreased from 2007 to 2019 in each age group (all p for trend < 0.001). In age- and sex-specific analyses, there were statistically significant decreases in the mean prevalence of dental caries for boys in all age groups (10–12 years: p for trend < 0.001; 13–15 years: p for trend < 0.001; 16–18 years: p for trend = 0.011). Likewise, there were statistically significant decreases in the mean prevalence of dental caries for girls in all age groups (10–12 years: p for trend < 0.001; 13–15 years: p for trend < 0.001; 16–18 years: p for trend < 0.001) (Fig. 2).

Trends in the mean prevalence of dental caries according to the presence of obesity or abdominal obesity or MetS in boys and girls

Table 3 presents the trends in the mean prevalence of dental caries in sex- and BMI-specific analyses from 2007 to 2019. Among boys with normal weight, there was a significant decrease in the mean prevalence of dental caries from 0.67 ± 0.04% to 0.44 ± 0.04% (β coefficient = − 0.016, p for trend < 0.001). However, no significant changes were observed in boys who were overweight (β coefficient = − 0.013, p for trend = 0.063) or obese (β coefficient = − 0.010, p for trend = 0.189). Similarly, for girls with normal weight, there was a significant decrease in the mean prevalence of dental caries from 0.73 ± 0.03% to 0.52 ± 0.04% (β coefficient = − 0.020, p for trend < 0.001). Conversely, no significant changes over time were found in girls who were overweight (β coefficient = − 0.002, p for trend = 0.845) or obese (β coefficient = − 0.011, p for trend = 0.418). These trends remained consistent even after adjusting for age, indicating a significant decrease in the prevalence of dental caries over time in both boys and girls with normal weight.

Table 4 displays the trends in the prevalence of dental caries in sex- and WC-specific analyses from 2007 to 2019. The results indicate that in boys without abdominal obesity, there was a significant decline in the mean prevalence of dental caries from 0.66 ± 0.04% to 0.46 ± 0.04% (β coefficient = − 0.015, p for trend < 0.001). Additionally, boys with abdominal obesity also showed a statistically significant decrease from 0.77 ± 0.07% to 0.63 ± 0.07% (β coefficient = − 0.013, p for trend = 0.027). Among girls, those without abdominal obesity

Characteristic	Boys Overall	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Unweighted number	5,147	274	617	658	535	454	425	431	328	340	253	263	253	316
Age, y	14.1 ± 2.6	13.8 ± 2.5	13.9 ± 2.6	14.1 ± 2.5	14.2 ± 2.6	14.2 ± 2.6	14.1 ± 2.4	14.1 ± 2.6	14.1 ± 2.5	14.2 ± 2.6	14.4 ± 2.6	14.5 ± 2.6	14.3 ± 2.6	14.2 ± 2.7
Height, cm	164.6 ± 12.7	163.2 ± 12.6	163.4 ± 13.3	164.8 ± 12.9	164.6 ± 12.5	164.5 ± 13.5	164.7 ± 12.3	164.8 ± 11.8	164.7 ± 12.2	164.3 ± 12.5	165.1 ± 12.5	166.7 ± 11.8	165.8 ± 12.9	165.3 ± 13.1
Weight, kg	58.0 ± 15.7	56.6 ± 16.1	57.0 ± 15.5	57.6 ± 14.9	57.2 ± 14.4	57.4 ± 16.5	57.1 ± 14.9	58.1 ± 16.1	58.5 ± 16.3	59.1 ± 16.3	57.9 ± 15.5	59.6 ± 14.9	60.5 ± 16.0	61.0 ± 17.0
SBP, mmHg	109.5 ± 10.6	106.7 ± 9.5	106.2 ± 10.7	110.2 ± 11.1	110.1 ± 11.9	108.9 ± 10.6	109.0 ± 9.9	110.4 ± 10.2	110.2 ± 10.3	111.1 ± 10.2	110.8 ± 9.5	110.3 ± 9.9	110.8 ± 10.4	112.0 ± 10.5
DBP, mmHg	67.0 ± 9.6	66.9 ± 10.1	66.3 ± 9.6	69.6 ± 8.7	67.9 ± 9.9	66.6 ± 9.8	65.6 ± 11.3	66.4 ± 9.2	66.5 ± 8.6	66.5 ± 9.1	67.5 ± 8.4	66.1 ± 9.1	66.8 ± 9.5	67.7 ± 9.8
BMI, kg/m^2	21.1 ± 4.0	20.9 ± 4.2	21.0 ± 3.8	20.9 ± 3.7	20.9 ± 3.7	20.8 ± 4.0	20.8 ± 3.6	21.1 ± 4.1	21.3 ± 4.2	21.6 ± 4.2	21.0 ± 4.0	21.2 ± 3.8	21.7 ± 4.0	22.0 ± 4.3
Obesity group[a]														
Normal	80.7	81.0	80.2	82.3	83.5	83.6	81.8	81.6	80.1	78.7	78.8	81.9	77.1	73.5
Overweight	12.1	10.7	14.7	12.3	11.6	9.4	12.7	11.1	10.2	10.7	15.3	11.5	13.0	15.8
Obese	7.2	8.3	5.1	5.4	4.9	6.9	5.5	7.2	9.7	10.6	6.0	6.6	9.9	10.7
WC, cm	72.2 ± 10.9	72.5 ± 11.7	71.8 ± 10.6	71.3 ± 10.0	71.1 ± 10.1	71.3 ± 11.0	70.7 ± 9.9	71.4 ± 11.1	72.5 ± 11.5	74.3 ± 11.2	73.0 ± 11.2	72.5 ± 10.5	73.8 ± 11.4	75.3 ± 11.8
Abdominal obesity[b]	16.1	18.6	15.3	14.4	12.6	15.5	13.1	11.8	17.2	19.1	18.5	13.7	21.5	23.5
Metabolic syndrome[c]	3.1	4.9	3.3	2.6	3.0	1.2	2.1	2.2	2.9	3.0	2.1	3.1	4.5	6.3
TC, mg/dL	155.7 ± 27.3	155.6 ± 26.5	155.8 ± 27.5	153.3 ± 29.6	151.9 ± 27.0	154.1 ± 29.2	153.3 ± 25.7	152.2 ± 25.0	150.3 ± 24.6	158.5 ± 27.1	160.4 ± 26.4	161.0 ± 25.9	163.9 ± 26.6	161.4 ± 28.0
TG, mg/dL	85.5 ± 53.8	88.2 ± 42.5	91.4 ± 76.7	86.5 ± 52.9	83.9 ± 48.4	76.9 ± 43.1	83.0 ± 44.7	83.3 ± 51.9	88.8 ± 61.5	87.1 ± 59.8	78.6 ± 40.9	84.7 ± 60.7	91.0 ± 50.5	89.6 ± 53.6
HDL-C, mg/dL	49.5 ± 9.7	48.1 ± 9.0	49.2 ± 9.4	47.8 ± 9.2	48.1 ± 8.7	50.4 ± 10.8	49.5 ± 9.8	50.4 ± 9.8	50.2 ± 9.5	51.1 ± 10.7	51.4 ± 9.7	49.8 ± 9.4	49.0 ± 8.9	50.9 ± 10.3
Tooth brush > = 3	32.5	26.2	30.6	34.5	23.5	20.6	31.4	36.2	34.6	42.6	34.7	42	41.1	40.2
Brushing before sleep	48.4	40.4	46.5	47.7	33.6	33.7	44.2	51.8	54	63.9	64.2	55.9	59.5	59.2
Household income[d]														
Low	12.2	13.2	11.4	14.6	16.5	16.5	9.2	11.2	8	12.6	7.5	10.2	11.1	12
Mid-low	26.4	29.1	21	19.8	30.2	27.5	24.3	34.5	27.6	25.7	24	26.8	21.4	30.8
Mid-high	31.1	27	33.6	32.9	26.9	31.3	31.5	26.8	38.1	31.7	31.8	30.3	35.5	28.8
High	30.4	30.7	34	32.6	26.5	24.7	35.1	27.4	26.3	30	36.7	32.8	32.1	28.4
Dental caries	60.8	68.4	60.1	64.9	65.3	65.0	65.9	58.7	54.8	53.8	56.0	54.2	45.4	50.0
Parental education level[e]														
Middle school	13.1	22.9	15.5	18	17.2	12.5	11.9	8.3	12	12.5	7.9	5.9	8	6.9
High school	43.7	43	50.4	45	43.7	46.2	43.1	50.8	46.6	42.8	34.4	42.8	33.1	36.1
College	43.2	34.1	34.1	37	39.1	41.3	44.9	40.8	41.5	44.7	57.6	51.3	59	57.1

Table 1. 1. Characteristics of study population: boys. Values are presented as weighted % (standard error) or weighted mean ± standard error. WC, waist circumference; SBP, systolic blood pressure; DBP, diastolic blood pressure; BMI, body mass index; TC, total cholesterol; TG, triglyceride; HDL-C, high-density lipoprotein cholesterol. [a]Categorized according to BMI percentile: normal, < 85th percentile; overweight, 85th to < 95th percentile; obese, ≥ 95th percentile. [b]Abdominal obesity was defined as WC > 90th percentile, using Korean WC reference data. [c]Metabolic syndrome was defined as combining central obesity with the presence of two or more of the other four risk factors, using IDF (International Diabetes Federation) criteria. For children aged 10 to 15 years, the following cutoffs were applied: WC ≥ 90th percentile; systolic BP ≥ 130 mmHg or diastolic BP ≥ 85 mmHg; triglycerides ≥ 150 mg/dL; HDL-C < 40 mg/dL; and fasting glucose ≥ 100 mg/dL. For adolescents older than 15 years: WC ≥ 90 cm for males, ≥ 80 cm for females; systolic BP ≥ 130 mmHg or diastolic BP ≥ 85 mmHg or treatment of previously diagnosed hypertension; fasting glucose ≥ 100 mg/dL or known type 2 diabetes; triglycerides ≥ 150 mg/dL or specific treatment for high triglycerides; HDL-C < 40 mg/dL in males, < 50 mg/dL in females, or specific treatment for low HDL-C. [d]Household income was calculated by dividing the household monthly income by the number of household members, and then categorized into quartiles: low, mid-low, mid-high, and high. [e]Parental education levels were categorized as middle school graduation, high school graduation, or college graduation.

experienced a significant decrease in the mean prevalence of dental caries from 0.72 ± 0.03% to 0.54 ± 0.04% (β coefficient = − 0.018, p for trend < 0.001), while no significant changes were observed in girls with abdominal obesity (β coefficient = − 0.003, p for trend = 0.748). Even after adjusting for age, the findings remained consistent, demonstrating significant decreases in the prevalence of dental caries over time for boys with or without abdominal obesity, as well as for girls without abdominal obesity.

Table 5 demonstrates the trends in the mean prevalence of dental caries in sex- and MetS-specific analyses from 2007 to 2019. Among boys without MetS, there was a significant decrease in the mean prevalence of dental caries from 0.68 ± 0.04% to 0.50 ± 0.03% (β coefficient = − 0.015, p for trend < 0.001). Conversely, no significant changes were observed in boys with MetS (β coefficient = − 0.019, p for trend = 0.154). Similarly, among girls without MetS, there was a significant decrease in the mean prevalence of dental caries from 0.72 ± 0.03% to 0.56 ± 0.04% (β coefficient = − 0.017, p for trend < 0.001), while no significant changes were observed in girls with MetS (β coefficient = − 0.010, p for trend = 0.694). Even after adjusting for age, the trends remained consistent, with significant decreases in the prevalence of dental caries observed over time for both boys and girls without MetS.

Discussion

This study aimed to examine the secular trend in dental caries among Korean children and adolescents aged 10–18 over a 13-year period. The mean prevalence of dental caries exhibited a significant decrease over the study period for both boys and girls. Furthermore, age-specific analyses revealed a significant decline in the mean prevalence of dental caries within each age group: 10–12, 13–15, and 16–18 years.

The decline in the prevalence of dental caries in Korean children and adolescents is consistent with the global trend in recent decades[5–7]. Fluoride toothpaste is known to be the most important cause of the decline in dental caries in developed countries in the 1970s and 1980s[14]. Lee and Han also demonstrated that fluoride toothpaste was a potential determinant of the decline in the number of dental caries cases in Korea[4].

Following the implementation of the Oral Health Act by the National Assembly of Korea in 2000, public oral health programs were introduced to reduce the incidence of dental caries. These programs included community water fluoridation, fluoride mouth rinsing, and a fissure sealant program, which were implemented in both urban and rural areas[15]. A study analyzing trends in adolescent health behaviors in Korea found an increase in post-lunch brushing, annual dental visits, annual sealants, and annual scaling from 2005 to 2009[16]. It is plausible that these public oral health programs and changes in adolescents' oral health behaviors likely contributed to the decreasing trends in dental caries.

Similar trends have been observed in other countries. Alsuraim et al. (2020) analyzed data from 46 countries from the 1990s to the 2010s and found a consistent decline in dental caries prevalence across 21 high-income and 25 middle- to low-income countries[5]. The decline was more pronounced in high-income countries, where a greater proportion of health expenditure is allocated to oral health, emphasizing curative and preventive oral care. Conversely, in middle- to low-income countries, healthcare spending is primarily being allocated towards emergency oral care and pain relief[17,18].

While a large-scale retrospective study in Henan Province, China, reported that the prevalence of dental caries increased from 39.75% in 2010 to 53.21% in 2019[19]. The highest prevalence was observed in medium-income areas, followed by high-income regions, whereas children from low-income areas had the lowest prevalence. This pattern suggests that economic growth without adequate preventive measures may increase dental caries risk, particularly in regions experiencing dietary transitions towards processed, high-sugar foods.

The relationship between obesity and dental caries has been widely debated, with conflicting findings across different populations. In our study, subgroup analyses after adjusting for age revealed that dental caries prevalence significantly decreased in the normal-weight group for both boys and girls. However, no significant decrease was observed in the overweight or obese groups. Additionally, a significant decrease in dental caries prevalence was noted in non-abdominal obesity and non-MetS groups, but not in the abdominal obesity group for girls or the MetS group for either sex. This pattern mirrors findings from Saudi Arabia, where a previous study of 380 children found that obese children had significantly higher mean dmft/DMFT scores compared to non-obese children[20]. However, BMI itself was not a statistically significant predictor of dental caries, suggesting that other factors such as diet, oral hygiene habits, and healthcare access may mediate the association between obesity and dental caries. In contrast, a recent study from China presents a different trend, showing that the prevalence of dental caries was highest among underweight children (OR = 1.10, 95% CI: 0.86–1.41), with an even greater risk observed in children with anemia (OR = 1.18, 95% CI: 0.98–1.42)[19]. These findings suggest that malnutrition may also increase the risk of dental caries in adolescents, potentially due to weakened enamel formation, reduced salivary function, and excessive sugar consumption[21]. Similarly, the Saudi Arabian national school screening study found that underweight children had the highest prevalence of dental caries, whereas overweight/obese children had a lower DMFT index[22].

Several mechanisms may explain the complex relationship between obesity and dental caries. Excessive intake of sweetened foods, a characteristic feature of the diet of individuals with obesity, is a well-established etiological factor for dental caries[2]. An increasing incidence of obesity and dental caries due to heightened and frequent consumption of sugary beverages and refined sugars has been consistently observed in numerous studies[23–25]. Furthermore, an escalated frequency of food intake and reduced intake intervals can decrease the oral pH, creating a conducive environment favorable for the growth and spread of *Streptococcus mutans*, a bacterial pathogen for dental caries. Therefore, frequent food intake plays a major role in the development and progression of dental caries, as well as in the pathogenesis of obesity in all population demographics[23–25]. Additionally, obesity can induce changes in the oral microflora and salivary properties, thereby acting as a potential predisposing factor for the development of dental caries in children[26–28].

Characteristic	Girls Overall	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Unweighted number	4,555	241	534	614	460	408	383	401	270	271	220	249	226	278
Age, y	14.1 ± 2.6	13.8 ± 2.7	13.9 ± 2.6	14.0 ± 2.5	14.0 ± 2.6	14.2 ± 2.6	14.2 ± 2.6	14.1 ± 2.6	14.0 ± 2.5	14.1 ± 2.5	14.1 ± 2.5	14.3 ± 2.6	14.4 ± 2.7	14.0 ± 2.7
Height, cm	157.0 ± 8.3	155.9 ± 8.3	156.0 ± 9.0	157.1 ± 8.4	157.0 ± 8.0	156.7 ± 8.5	157.5 ± 8.0	157.0 ± 8.6	156.9 ± 8.3	157.3 ± 7.6	157.8 ± 8.2	157.6 ± 7.8	158.3 ± 7.9	157.5 ± 8.5
Weight, kg	50.5 ± 11.4	49.1 ± 10.2	48.7 ± 11.0	49.9 ± 11.2	50.1 ± 11.1	50.7 ± 11.7	50.3 ± 10.6	50.4 ± 10.6	50.5 ± 11.4	52.5 ± 11.6	51.1 ± 12.0	52.2 ± 12.1	51.5 ± 10.8	51.5 ± 13.7
SBP, mmHg	104.4 ± 9.3	102.1 ± 8.8	100.6 ± 9.1	104.6 ± 9.7	104.0 ± 9.8	103.9 ± 9.3	105.4 ± 9.0	105.1 ± 9.0	104.9 ± 8.5	106.4 ± 8.2	107.1 ± 11.0	105.8 ± 8.8	105.5 ± 9.4	105.3 ± 9.0
DBP, mmHg	65.6 ± 8.4	64.4 ± 8.7	63.7 ± 8.4	67.3 ± 7.9	65.5 ± 8.4	65.3 ± 8.4	66.0 ± 9.3	65.6 ± 8.3	64.8 ± 8.4	66.2 ± 7.7	66.3 ± 8.1	66.3 ± 7.6	66.4 ± 8.7	65.8 ± 8.3
BMI, kg/m^2	20.3 ± 3.5	20.1 ± 3.3	19.8 ± 3.3	20.0 ± 3.3	20.2 ± 3.5	20.5 ± 3.6	20.1 ± 3.3	20.3 ± 3.1	20.3 ± 3.5	21.1 ± 3.7	20.3 ± 3.7	20.9 ± 3.9	20.4 ± 3.5	20.5 ± 4.3
Obesity group[a]														
Normal	87.4	87.5	91.2	90.5	88.6	86.1	87.5	91.1	88.0	83.3	88.5	79.8	86.8	82.9
Overweight	8.9	11.8	6.4	6.5	7.0	9.8	9.7	6.4	8.7	10.0	4.9	15.5	9.4	10.7
Obese	3.7	0.7	2.3	3.0	4.4	4.1	2.8	2.4	3.3	6.7	6.6	4.7	3.8	6.4
WC, cm	67.4 ± 8.6	68.1 ± 8.5	66.6 ± 8.3	66.5 ± 8.3	67.1 ± 8.8	67.5 ± 8.8	66.5 ± 7.7	66.6 ± 7.9	67.5 ± 8.2	70.0 ± 8.8	68.2 ± 9.2	67.8 ± 9.2	66.9 ± 8.0	68.4 ± 9.8
Abdominal obesity [b]	4.9	5.0	3.5	3.8	5.8	5.2	2.0	3.2	4.2	8.2	9.2	6.2	3.7	7.4
Metabolic syndrome [c]	1.2	0.9	1.5	1.4	1.0	1.8	0.0	1.2	0.6	0.7	3.2	0.8	1.1	2.5
TC, mg/dL	164.1 ± 26.4	163.6 ± 25.7	159.0 ± 24.9	162.5 ± 26.0	163.0 ± 23.4	162.5 ± 26.3	165.4 ± 29.1	161.6 ± 24.6	165.1 ± 27.6	164.6 ± 26.1	168.7 ± 29.8	169.1 ± 26.8	166.9 ± 27.4	167.3 ± 26.3
TG, mg/dL	87.1 ± 49.1	97.0 ± 49.9	89.2 ± 62.5	87.7 ± 45.9	85.6 ± 59.4	85.7 ± 46.7	86.7 ± 47.2	81.2 ± 41.5	83.0 ± 41.8	88.7 ± 46.0	88.4 ± 46.0	84.9 ± 42.7	86.5 ± 49.7	84.5 ± 44.4
HDL-C, mg/dL	52.5 ± 10.0	50.4 ± 9.6	50.6 ± 9.1	51.0 ± 9.5	50.8 ± 9.3	52.1 ± 10.6	54.6 ± 11.3	53.8 ± 9.7	53.9 ± 9.7	52.1 ± 9.6	54.7 ± 10.7	53.0 ± 9.7	53.2 ± 9.8	54.8 ± 10.2
Tooth brush > = 3	49.8	44.9	45	49.6	41.6	45.8	49.9	63.6	46.2	54.9	51.1	50	54.6	57
Brushing before sleep	50.3	43.2	47.7	53.6	32.5	32.2	52.3	57.9	50.2	58	63	62.9	64.5	57.9
Household income[d]														
Low	13	9.7	9.4	14.7	19.6	14.5	14.8	12.3	12.3	15.3	11	11.2	12.7	8.6
Mid-low	26	25.1	25.4	24.8	32.1	32.2	27.9	29.4	18.3	24.7	20.6	20.3	24.4	26
Mid-high	31.8	34.1	35.2	30.5	25.5	30.6	31.1	29.7	39.2	30	28.2	32.5	37.5	30.5
High	29.2	31	30	30	22.8	22.7	26.3	28.6	30.1	29.9	40.2	36.1	25.4	34.9
Dental caries	68.4	72.1	74.0	74.4	74.8	67.7	75.4	70.0	60.7	59.7	51.6	65.6	51.7	55.9
Parental education level[e]														
Middle school	11	18.3	15.3	10.9	17.3	15.3	10.5	8.7	7.1	8.3	6.4	4.3	7.5	4.2
High school	45.6	47.4	48.4	51.4	48.4	48.2	49.9	54.8	40.9	45.2	37.8	38.8	34.8	32.7
College	43.3	34.2	36.4	37.7	34.3	36.4	39.6	36.5	52	46.5	55.8	56.9	57.8	63.1

Table 2. Characteristics of study population: girls. Values are presented as weighted % (standard error) or weighted mean ± standard error. WC, waist circumference; SBP, systolic blood pressure; DBP, diastolic blood pressure; BMI, body mass index; TC, total cholesterol; TG, triglyceride; HDL-C, high-density lipoprotein cholesterol. [a]Categorized according to BMI percentile: normal, < 85th percentile; overweight, 85th to < 95th percentile; obese, ≥ 95th percentile. [b]Abdominal obesity was defined as WC > 90th percentile, using Korean WC reference data. [c]Metabolic syndrome was defined as combining central obesity with the presence of two or more of the other four risk factors, using IDF (International Diabetes Federation) criteria. For children aged 10 to 15 years, the following cutoffs were applied: WC ≥ 90th percentile; systolic BP ≥ 130 mmHg or diastolic BP ≥ 85 mmHg; triglycerides ≥ 150 mg/dL; HDL-C < 40 mg/dL; and fasting glucose ≥ 100 mg/dL. For adolescents older than 15 years: WC ≥ 90 cm for males, ≥ 80 cm for females; systolic BP ≥ 130 mmHg or diastolic BP ≥ 85 mmHg or treatment of previously diagnosed hypertension; fasting glucose ≥ 100 mg/dL or known type 2 diabetes; triglycerides ≥ 150 mg/dL or specific treatment for high triglycerides; HDL-C < 40 mg/dL in males, < 50 mg/dL in females, or specific treatment for low HDL-C. [d]Household income was calculated by dividing the household monthly income by the number of household members, and then categorized into quartiles: low, mid-low, mid-high, and high. [e]Parental education levels were categorized as middle school graduation, high school graduation, or college graduation.

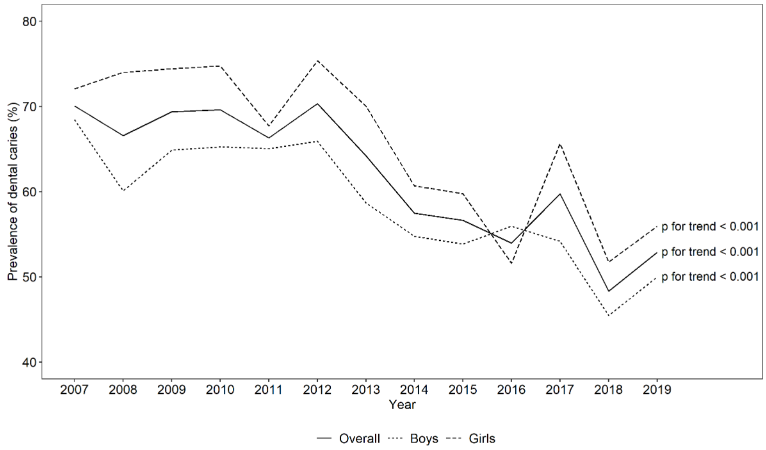

Fig. 1. Trends in the mean prevalence of dental caries in boys and girls from 2007 to 2019.

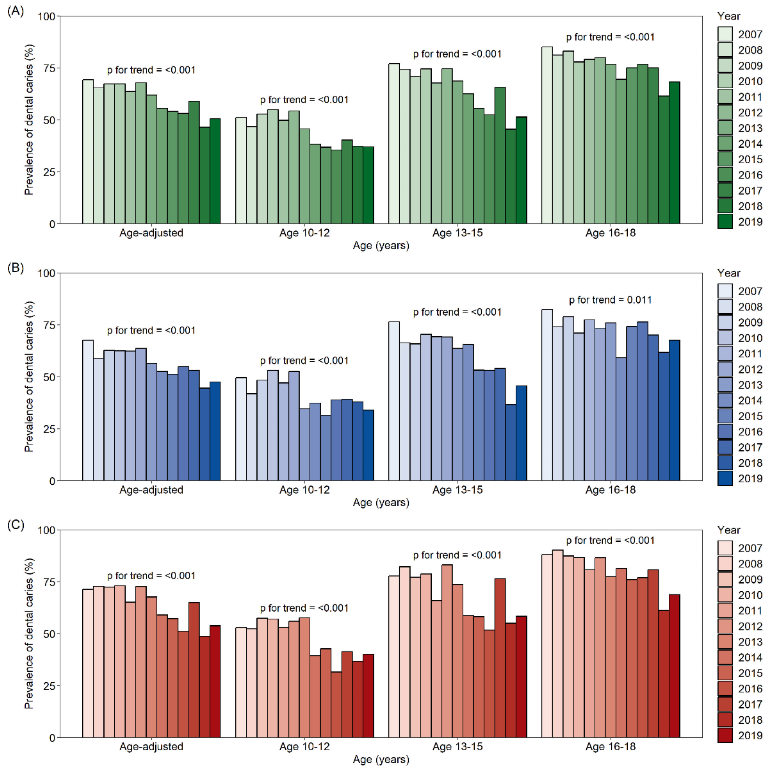

Fig. 2. Trends in the mean prevalence of dental caries according to age from 2007 to 2019 in (A) all study participants, (B) boys, and (C) girls.

Economic freedom and trade liberalization policies have increased the availability of sugary and processed foods with low nutritional value, contributing to the rise in obesity and other non-communicable diseases[29,30]. Both obesity and dental caries share common risk factors, including behavioral and socioeconomic characteristics. Socioeconomic factors influence dietary choices, affecting the development of obesity and dental caries[31]. Several studies have examined the correlation between dental caries and obesity in children and adolescents[8,9].

A meta-analysis published in 2019 indicated that individuals with MetS tend to have fewer teeth and a higher likelihood of lacking functional dentition compared to their peers in the adult population[32]. According to the study by Souza et al., MetS has been identified as a factor influencing tooth loss, a consequence of dental caries or periodontitis, in the adult population[33]. This finding can explain why the prevalence of dental caries did not decrease in the MetS group in our study. There are several plausible explanations for the association between MetS and dental caries. MetS is characterized by an elevation in oxidative stress, contributing to impaired inflammation, vascular function, and atherosclerosis[34]. This oxidative stress induces chronic systemic

Group[a]	Dental caries (weighted % ± standard error)													Age-unadjusted		Age-adjusted	
	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	coefficient	*p* for trend	coefficient	*p* for trend
Boys																	
Normal	0.67 ± 0.04	0.59 ± 0.02	0.64 ± 0.03	0.65 ± 0.03	0.65 ± 0.03	0.67 ± 0.03	0.58 ± 0.03	0.53 ± 0.03	0.53 ± 0.04	0.56 ± 0.04	0.55 ± 0.04	0.47 ± 0.04	0.44 ± 0.04	− 0.016	< 0.001	− 0.017	< 0.001
Overweight	0.60 ± 0.10	0.65 ± 0.06	0.71 ± 0.06	0.71 ± 0.07	0.59 ± 0.09	0.65 ± 0.08	0.44 ± 0.10	0.59 ± 0.10	0.38 ± 0.09	0.60 ± 0.10	0.49 ± 0.10	0.48 ± 0.10	0.60 ± 0.09	− 0.013	0.063	− 0.012	0.061
Obese	0.96 ± 0.04	0.65 ± 0.10	0.62 ± 0.10	0.49 ± 0.10	0.76 ± 0.09	0.58 ± 0.10	0.89 ± 0.06	0.61 ± 0.11	0.79 ± 0.07	0.46 ± 0.15	0.52 ± 0.14	0.48 ± 0.11	0.73 ± 0.09	− 0.010	0.189	− 0.011	0.137
Girls																	
Normal	0.73 ± 0.03	0.74 ± 0.02	0.74 ± 0.02	0.74 ± 0.03	0.69 ± 0.03	0.75 ± 0.03	0.69 ± 0.03	0.60 ± 0.04	0.57 ± 0.04	0.49 ± 0.04	0.63 ± 0.05	0.52 ± 0.05	0.52 ± 0.04	− 0.020	< 0.001	− 0.020	< 0.001
Overweight	0.66 ± 0.13	0.76 ± 0.07	0.79 ± 0.07	0.78 ± 0.08	0.61 ± 0.09	0.80 ± 0.09	0.72 ± 0.11	0.62 ± 0.12	0.63 ± 0.10	0.61 ± 0.15	0.75 ± 0.08	0.52 ± 0.12	0.76 ± 0.09	− 0.002	0.845	− 0.004	0.621
Obese	1.00 ± 0.00	0.88 ± 0.07	0.73 ± 0.12	0.84 ± 0.10	0.67 ± 0.14	0.75 ± 0.17	0.91 ± 0.09	0.81 ± 0.12	0.85 ± 0.09	0.78 ± 0.13	0.94 ± 0.06	0.43 ± 0.18	0.65 ± 0.17	− 0.011	0.418	− 0.013	0.309

Table 3. Trends in prevalence of dental caries by sex and obesity subgroups. [a]Categorized according to body mass index percentile: normal, < 85th percentile; overweight, 85th to < 95th percentile; obese, ≥ 95th percentile, based on the 2017 Korean National Growth Charts.

inflammation, which can impact the salivary glands, leading to hyposalivation. Consequently, this condition increases the susceptibility to dental caries and subsequent tooth loss[35,36]. Furthermore, chronic systemic inflammation impairs the individual's immune response, thereby escalating the risk of oral diseases[35,36].

Nasir Z. Bashir reported a higher prevalence of dental caries in permanent teeth among girls compared to boys[6]. This may explain the finding that among the abdominal obesity group in this study, the prevalence of dental caries decreased only in boys and not in girls. The increased vulnerability of girls to dental caries may be attributed to the early eruption of permanent teeth in females, leading to prolonged exposure to a cariogenic oral environment[37]. Additionally, hormonal fluctuations during puberty and differences in salivary flow rates between females and males could contribute to this sex-based distinction[38].

Given the strong association between metabolic abnormalities and dental caries, targeted prevention strategies are essential, particularly for high-risk children. Based on our findings, several key approaches can be recommended to mitigate the risk of dental caries in this population. First, nutritional education programs should be implemented to reduce the consumption of sugary and processed foods, which are common risk factors for both dental caries and metabolic abnormalities. Second, regular oral health check-ups should be emphasized to enable early detection and management of dental caries, particularly among children with obesity, abdominal obesity, and MetS. Finally, a multidisciplinary approach involving pediatricians, dentists, and nutritionists is crucial for integrating oral health into the comprehensive management of metabolic disorders.

There are some limitations to this study. First, since the sample consisted of Korean children and adolescents, further research is needed to assess whether these findings can be generalized to other races or ethnic groups. Second, our study was limited to identifying trends in dental caries; the exact etiology of the observed trends in dental caries prevalence among individuals with obesity, central obesity, or MetS could not be determined. Nevertheless, this study is the first report evaluating trends in dental caries prevalence according to age, sex, obesity, abdominal obesity, and MetS in Korean children and adolescents based on multi-year data at the national level. The data were collected from nearly 10,000 individuals over a prolonged period exceeding 10 years, making the data highly reliable.

Conclusion

The prevalence of dental caries has significantly declined among Korean children and adolescents over the past 13 years, with a consistent trend across sex and age subgroups. This positive development is evident in individuals without metabolic abnormalities, where the prevalence of dental caries has continued to decrease. However, in subgroups with obesity or overweight, abdominal obesity, or MetS, the prevalence of dental caries has remained stagnant.

The findings of this study provide crucial insights into the factors influencing dental caries among pediatric populations and can inform preventive and therapeutic strategies tailored to specific demographic groups. Implementing effective measures to address both metabolic abnormalities and dental caries in children and adolescents is essential to safeguard their oral health and overall well-being.

Methods

Study design and subjects

This cross-sectional study utilized data from 105,732 participants of the Korean National Health and Nutrition Examination Survey (KNHNES) conducted between 2007 and 2019. Managed by the Korea Centers for Disease Control and Prevention, this surveillance system collects information on health-related behaviors, health examination outcomes, socioeconomic status, and nutritional interviews for the Korean population. For this study, participants aged 10 to 18 years were included ($N = 11{,}457$), while those with incomplete oral examination data were excluded ($N = 1{,}755$). Ultimately, a total of 9,702 participants were included in the analysis. The number of participants included in the study for each survey year is presented in Fig. 3.

Assessment of dental caries

The presence of dental caries was assessed using the DMFT (Decayed, Missing, and Filled Teeth) scoring variable. The DMFT index, established by the World Health Organization (WHO) and widely recognized for diagnosing dental caries[39], is a critical indicator of individual dental health. It represents the number of decayed, missing, and filled teeth in the permanent dentition, encompassing both untreated and treated caries. Trained dentists examined DMFT scores using a dental mirror under fluorescent light[40]. The index values were then categorized into two groups: individuals with current or past caries experience (DMFT $\geq$ 1) and those who had never experienced caries (DMFT = 0). Additionally, the frequency of toothbrushing was classified as either more than 3 times a day or brushing before sleep.

Anthropometric measurements and laboratory tests

Trained medical personnel conducted the measurement of height, weight, and waist circumference (WC). Height was measured using a stadiometer, Seca 225 (Seca, Hamburg, Germany), with a precision of 0.1 cm. Weight was measured using an electronic balance, GL-6000-20 (G-tech, Seoul, Korea), with a precision of 0.1 kg. Body mass index (BMI) was calculated as weight (kg) divided by the square of height (m^2). WC was measured with a flexible tape, Seca 220 (Seca, Hamburg, Germany), with a precision of 0.1 cm at the midpoint between the lowest margin of the rib and the highest margin of the iliac crest during expiration. Blood pressure (BP) was measured on the right arm using a mercury sphygmomanometer with a cuff appropriate for the arm circumference. Prior to measurement, participants rested in a seated position for at least 5 min (Baumanometer sphygmomanometer; W.A. Baum Co Inc., Copiague, NY, USA, and Littmann Stethoscopes; 3 M, Maplewood, MN, USA).

Group[a]	Dental caries (weighted % ± standard error)													Age-unadjusted		Age-adjusted	
	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	Coefficient	*p* for trend	Coefficient	*p* for trend
Boys																	
Abdominal obesity	0.77 ± 0.07	0.64 ± 0.06	0.69 ± 0.06	0.64 ± 0.07	0.65 ± 0.07	0.64 ± 0.07	0.71 ± 0.08	0.59 ± 0.08	0.59 ± 0.07	0.59 ± 0.09	0.52 ± 0.09	0.36 ± 0.08	0.63 ± 0.07	− 0.013	0.027	− 0.013	0.018
Non-abdominal obesity	0.66 ± 0.04	0.59 ± 0.02	0.64 ± 0.03	0.65 ± 0.03	0.65 ± 0.03	0.66 ± 0.03	0.57 ± 0.03	0.54 ± 0.03	0.53 ± 0.04	0.56 ± 0.04	0.54 ± 0.04	0.48 ± 0.04	0.46 ± 0.04	− 0.015	< 0.001	− 0.016	< 0.001
Girls																	
Abdominal obesity	0.71 ± 0.15	0.81 ± 0.08	0.94 ± 0.04	0.87 ± 0.07	0.66 ± 0.12	0.70 ± 0.17	0.70 ± 0.19	0.77 ± 0.14	0.81 ± 0.08	0.72 ± 0.13	0.96 ± 0.04	0.25 ± 0.12	0.79 ± 0.12	− 0.003	0.748	− 0.003	0.778
Non-abdominal obesity	0.72 ± 0.03	0.74 ± 0.02	0.74 ± 0.02	0.74 ± 0.02	0.68 ± 0.03	0.75 ± 0.03	0.70 ± 0.03	0.60 ± 0.03	0.58 ± 0.04	0.50 ± 0.04	0.64 ± 0.04	0.52 ± 0.04	0.54 ± 0.04	− 0.018	< 0.001	− 0.019	< 0.001

Table 4. Trends in prevalence of dental caries according to sex and abdominal obesity. [a]Abdominal obesity was defined as a waist circumference ≥ 90th percentile, using Korean waist circumference reference data.

Blood samples were collected from participants after a minimum 8-hour fasting period by a skilled nurse and promptly transported to the Central Laboratory (NEODIN Medical Institute, Seoul, Korea). The assessment of each component of the MetS diagnostic criteria, including fasting plasma glucose (FPG), high-density lipoprotein cholesterol (HDL-C), and triglyceride (TG) concentrations, was performed using different analyzers depending on the time period: ADIVIA 1650 (Siemens, Buffalo Grove, USA) from 2007 to 2008.02.15., Hitachi Automatic Analyzer 7600 (Hitachi, Tokyo, Japan) from 2008.02.20. to 2012, Hitachi Automatic Analyzer 7600 – 210 (Hitachi, Tokyo, Japan) from 2013 to 2018, and Labospect 008AS (Hitachi, Tokyo, Japan) in 2019.

Household income was evaluated based on the monthly average household equalized income, calculated by dividing the monthly income by the number of household members. The income was categorized into quartiles on a yearly basis, with the quartiles designated as low, mid-low, mid-high, and high. Parental education levels were categorized as middle school graduation, high school graduation, or college graduation.

Definitions of obesity, abdominal obesity, and MetS

According to the 2017 Korean National Growth Charts, the study participants were categorized into different obesity groups based on their BMI percentiles. The groups were defined as follows: normal (BMI less than the 85th percentile), overweight (BMI between the 85th and less than the 95th percentile), and obese (BMI equal to or greater than the 95th percentile)[41]. Abdominal obesity was determined by a waist circumference (WC) equal to or greater than the 90th percentile for age and sex[42].

There are no standardized criteria for diagnosing MetS in children and adolescents. However, commonly used criteria include the modified NCEP-ATP III (National Cholesterol Education Program Adult Treatment Panel III) criteria[43] and the IDF (International Diabetes Federation) criteria[44]. In this study, the IDF criteria were utilized, which involves the combination of central obesity with the presence of two or more of the other four risk factors[44]. For children aged 10 to 15 years, the following cutoffs were applied: WC ≥ 90th percentile, systolic BP ≥ 130 mmHg or diastolic BP ≥ 85 mmHg, triglycerides ≥ 150 mg/dL, HDL-C < 40 mg/dL, and fasting glucose ≥ 100 mg/dL. For adolescents older than 15 years, the IDF recommended the same criteria used in adults: central obesity (WC ≥ 90 cm for males, ≥ 80 cm for females), alongside at least two of the following risk factors: high BP (systolic BP ≥ 130 mmHg or diastolic BP ≥ 85 mmHg or treatment of previously diagnosed hypertension), fasting glucose ≥ 100 mg/dL or known type 2 diabetes, triglycerides ≥ 150 mg/dL or specific treatment for high triglycerides, HDL-C < 40 mg/dL in males and < 50 mg/dL in females, or specific treatment for low HDL-C[44].

Statistical analysis

The KNHANES data was analyzed using sample weights to ensure a representative sample of the Korean population. Complex sampling was accounted for by employing sampling weights. The baseline characteristics of the study population were presented as the mean ± standard error (SE) for continuous variables and as percentages for categorical variables. A linear regression model was utilized to examine the linear trends in prevalence dental caries across various factors such as sex, obesity subgroup, MetS, and abdominal obesity with age adjustment. Subgroup analysis based on age was performed separately for men and women. Statistical significance was determined using a p-value threshold of 0.05, with all statistical tests being two-sided. The statistical analyses were carried out using R software, version 4.3.0, provided by the R Foundation for Statistical Computing in Vienna, Austria, http://www.R-project.org).

Group[a]	Dental caries (weighted % ± standard error)													Age-unadjusted		Age-adjusted	
	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	Coefficient	*p* for trend	Coefficient	*p* for trend
Boys																	
Metabolic syndrome	0.80 ± 0.18	0.59 ± 0.14	0.67 ± 0.13	0.66 ± 0.14	0.71 ± 0.20	0.62 ± 0.21	0.75 ± 0.17	0.67 ± 0.20	0.65 ± 0.15	0.59 ± 0.25	0.65 ± 0.18	0.34 ± 0.15	0.49 ± 0.14	− 0.019	0.154	− 0.019	0.150
Non-metabolic syndrome	0.68 ± 0.04	0.60 ± 0.02	0.65 ± 0.02	0.65 ± 0.03	0.65 ± 0.03	0.66 ± 0.03	0.58 ± 0.03	0.54 ± 0.03	0.54 ± 0.04	0.56 ± 0.04	0.54 ± 0.03	0.46 ± 0.04	0.50 ± 0.03	− 0.015	< 0.001	− 0.015	< 0.001
Girls																	
Metabolic syndrome	0.37 ± 0.33	0.66 ± 0.18	1.00 ± 0.00	1.00 ± 0.00	0.70 ± 0.27	NA	0.77 ± 0.21	1.00 ± 0.00	1.00 ± 0.00	0.30 ± 0.27	0.77 ± 0.22	0.00 ± 0.00	0.66 ± 0.28	− 0.010	0.694	− 0.018	0.403
Non-metabolic syndrome	0.72 ± 0.03	0.74 ± 0.02	0.74 ± 0.02	0.74 ± 0.02	0.68 ± 0.03	0.75 ± 0.03	0.70 ± 0.03	0.60 ± 0.03	0.59 ± 0.04	0.52 ± 0.04	0.65 ± 0.04	0.52 ± 0.04	0.56 ± 0.04	− 0.017	< 0.001	− 0.018	< 0.001

Table 5. Trends in prevalence of dental caries according to sex and metabolic syndrome. [a]Metabolic syndrome was defined as combining central obesity with the presence of two or more of the other four risk factors, using IDF (International Diabetes Federation) criteria. For children aged 10 to 15 years, the following cutoffs were applied: WC ≥ 90th percentile; systolic BP ≥ 130 mmHg or diastolic BP ≥ 85 mmHg; triglycerides ≥ 150 mg/dL; HDL-C < 40 mg/dL; and fasting glucose ≥ 100 mg/dL. For adolescents older than 15 years: WC ≥ 90 cm for males, ≥ 80 cm for females; systolic BP ≥ 130 mmHg or diastolic BP ≥ 85 mmHg or treatment of previously diagnosed hypertension; fasting glucose ≥ 100 mg/dL or known type 2 diabetes; triglycerides ≥ 150 mg/dL or specific treatment for high triglycerides; HDL-C < 40 mg/dL in males, < 50 mg/dL in females, or specific treatment for low HDL-C.

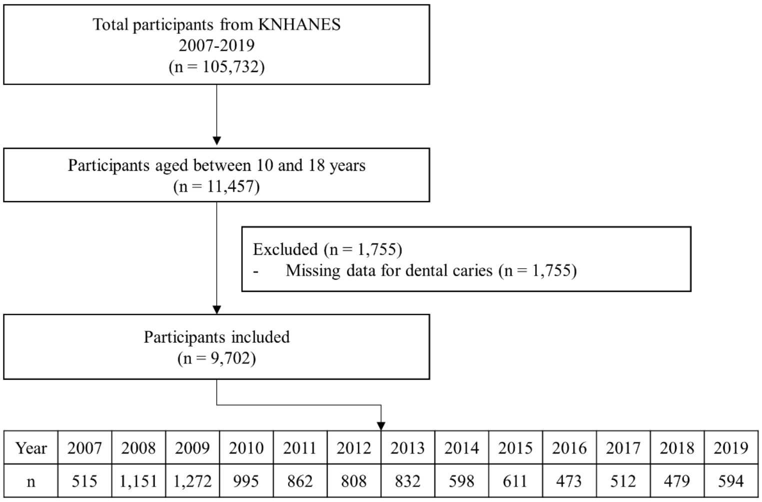

Fig. 3. Flow chart of study population.

Data availability
The data analyzed in this study were obtained from the Korea National Health and Nutritional Examination Survey and are available at the following website: http://www.kdca.go.kr.

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Declarations.

Author contributions
YJK, and JWL contributed to the conceptualization of this work. YJL analyzed the data. SYC, YJL, YJK, and JWL contributed to the acquisition and interpretation of the data and the drafting of the manuscript. All authors critically revised the manuscript, provided final approval, and agreed to hold accountability for all aspects of the work, as well as ensuring its integrity and accuracy.

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Competing interests
The authors declare no competing interests.

Ethical approval
This study was conducted in accordance with the principles of the Declaration of Helsinki and received approval from the Institutional Review Board (IRB) of Severance Hospital (IRB No. 4-2023-1115). Written informed consent was obtained from all participants or legal representatives of the children enrolled in this study.

Additional information
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