

POPULATION STUDY ARTICLE



Impact of exposure to secondhand smoke on the risk of obesity in early adolescence

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BACKGROUND: Exposure to secondhand smoke (SHS) might be associated with obesity in children. This study aimed to evaluate whether continuous, quit, or start exposure to SHS was associated with obesity risk in early adolescents.

METHODS: We used population-based longitudinal data of primary school students in Adachi City, Tokyo, Japan, in 2018 (4th grade) and 2020 (6th grade) and studied 3605 students. The association between continuous, quit, start, or never exposed to SHS from 4th to 6th grade and BMI categories (underweight or normal weight, overweight, obesity) in 6th grade was investigated using ordinal logistic regression models.

RESULTS: Continuous SHS group showed a higher risk of being in the high BMI category than no SHS group (OR = 1.51, 95% CI 1.16–1.96). The stratified analyses by sex showed a similar association in boys (OR = 1.74, 95% CI 1.25–2.44) but not in girls (OR = 1.14, 95% CI 0.74–1.76). Quitting SHS group did not show a higher risk of being in the high BMI category than no SHS group (OR = 1.11, 95% CI 0.75–1.66) and the same was true for boys (OR 1.46, 95% CI 0.88–2.41).

CONCLUSIONS: Continuous SHS was a risk factor for obesity in boys in early adolescence; however, quitting SHS may help prevent it.

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IMPACT:

- Continuous secondhand smoke (SHS) was not associated with a higher risk of obesity in early adolescence in girls.
- Continuous SHS can be a risk factor for obesity in early adolescence in boys.
- Quitting SHS may help to prevent obesity in early adolescence in boys.

INTRODUCTION

Globally, the prevalence of childhood obesity had noticeably risen from 4% in 1975 to 18% in 2016. It was estimated that 124 million children and adolescents aged 5–19 years worldwide were obese, and 213 million were overweight in 2016.^{1,2} Childhood obesity is a significant risk factor for many adverse health outcomes such as type 2 diabetes, hypertension, dyslipidemia, cardiovascular disease (CVD), and all-cause mortality in adulthood.^{2–4} Strategies for preventing and managing childhood obesity are subjected to public health guidelines in some countries,^{2,5,6} and primordial prevention is increasingly emphasized to promote cardiovascular health in children.⁷ Therefore, it is necessary to clarify the modifiable factors to prevent obesity in children.

Among several possible risk factors for childhood obesity, secondhand smoke (SHS) may be a possible modifiable risk factor.^{8–12} SHS is a major public health problem in children.^{13,14} The prevalence of SHS exposure in children worldwide reached 40%;¹⁴ in Japan, smoking prevalence in parents during childcare remained high in 2017 (paternal smoking: 37.7%, maternal smoking: 6.4%).¹⁵ In several longitudinal studies, children exposed

to SHS had a higher body mass index (BMI) z-score and risk of obesity than unexposed children (aged 4–18 years).^{8–12} However, the impact of changes in SHS status on the risk of obesity is unclear, i.e., whether improvements in SHS lead to a lower risk of obesity or worsening SHS leads to a higher risk of obesity. Assessing the impact of changes in SHS status on the risk of obesity will provide critical information for future public health measures for childhood obesity. In addition, it is important to focus on the BMI of early adolescence because, in Japanese children, early adolescence could be a critical period for future obesity risk.¹⁶

The COVID-19 pandemic may be a suitable situation for assessing the impact of changes in SHS status. During the COVID-19 pandemic, exposure to SHS at home is expected to increase because family members spend more time together at home^{17–19} due to decreased frequency of going out and increased frequency of working from home. On the other hand, some smokers may try to quit smoking because smoking is a risk factor for severe COVID-19 infection²⁰ or are concerned about SHS exposure's impact on their families.^{17,18} In other words, the SHS status may have changed.

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Notably, most previous studies were conducted in western countries, with similar studies remaining scarce in Asian countries. The effects of SHS on energy metabolism might vary by ethnicity. Benzo[a]pyrene (B[a]P), a typical carcinogen abundant in side-stream smoke,²¹ inhibited the β -adrenergic stimulation of lipolysis in adipose tissue in mice, suggesting that it may affect weight gain.²² Interestingly, the Trp64Arg variant in β -3 adrenergic receptor (ADRB3), which plays an important role in energy metabolism by regulating lipolysis and thermogenesis,²³ could be associated with BMI in East Asians but not in Europeans.^{24,25} The risk of obesity to developing CVD risk factors could also vary by ethnicity.^{26,27} Asians could have a higher risk of developing diabetes for the same increase in BMI than whites, blacks, and Hispanics.²⁷ Thus, the effect of SHS on obesity in Asians should also be evaluated.

In this study, we used population-based longitudinal data of later primary school students from the Adachi Child Health Impact of Living Difficulty (A-CHILD) study in Tokyo, Japan. The A-CHILD study includes the data on exposure to SHS and BMI before and during the COVID-19 pandemic in 2018 and 2020. The objective of our study is to elucidate whether continuous, quit, or start of exposure to SHS, observed during the COVID-19 pandemic, was associated with BMI z-score from the 4th grade to 6th grade in primary school children.

METHODS

Study design and subjects

We used longitudinal data from the A-CHILD study conducted in Adachi City, Tokyo, Japan, in 2018 and 2020 (see protocol paper for details²⁸). The survey covered all 69 public elementary schools established in Adachi City. Self-report questionnaires with unique anonymous IDs were distributed in October 2018 (4th grade), and October 2020 (6th grade), and students and their parents completed the questionnaires. In 2018, 4290 out of 5311 4th grade students (response rate 80.8%), and in 2020, 4489 out of 5355 6th grade students (response rate 83.8%), responded. We included in our analysis 3605 students with SHS data at 4th and 6th grade and with BMI data at 6th grade.

Outcome measurement

Children's height and weight were measured by school teachers during a school health checkup in elementary school, following a standardized protocol. Height was measured to the nearest 0.1 cm using a portable height meter, and weight was measured to the nearest 0.1 kg using a digital scale, without shoes and in light clothing. Child BMI was calculated using height and weight and assessed as a z-score based on the WHO Child Growth Standards specific to age and sex.²⁹ We classified BMI in 6th grade into three categories based on the cut points from the WHO definitions of overweight and obesity:³⁰ <1 SD, 1–2 SD, and \geq 2 SD.

Measurement of exposure

Exposure to SHS was assessed by asking the student's caregivers the following questions. "How often does your family smoke in front of your child?". Although we did not specifically ask who the smoker was, 97.8% of the children lived with their mothers, 89.6% lived with their fathers, 9.3% lived with their grandmothers, and 5.4% lived with their grandfathers, suggesting that in most families, it is the parent who smoked in front of the children. The responses to this question were "often", "sometimes", "rarely" and "never". We categorized "often", "sometimes" and "rarely" as "exposure to SHS" and "never" as "not exposed to SHS". Using "exposure to SHS" and "not exposed to SHS" from 4th grade to 6th grade, we categorized the participants into four groups: "No SHS from 4th to 6th grades", "Start SHS from 4th grade to 6th grade", "Quit SHS from 4th grade to 6th grade", and "Continuous SHS from 4th to 6th grade".

A validation study conducted in Japan³¹ assessed the accuracy of self-reported questionnaires on smoking in pregnant women by using urinary cotinine levels as a gold standard for distinguishing between active and passive smokers. When the cutoff value was at 36.8 μ g/g-creatinine, this questionnaire had a positive predictive value (PPV) of 0.967 and a negative predictive value (NPV) of 0.957 to distinguish between active and passive smokers and nonsmokers. When the cutoff value was set to 0.31 μ g/g-

creatinine, the PPV and NPV that distinguished passive smokers and nonsmokers were 0.868 and 0.644, respectively. In the validation study, pregnant women's exposure to SHS was assessed by whether they were exposed to SHS from those around them. In our study, on the other hand, to assess the extent to which children were exposed to SHS, we assessed children's exposure to SHS by the number of cigarettes smoked by their caregivers in front of the children. Because of the high accuracy of the questionnaire in the validation study in distinguishing active and passive smokers from nonsmokers, we used the questionnaire method in our study to assess whether children were exposed to SHS.

Covariates

Child sex, socioeconomic status (SES) such as annual household income and mother's education, mother's age, family history of obesity, BMI in 4th grade, lifestyle habits such as exercise, screen time, sugar-sweetened beverages consumption, were used as covariates based on the previous studies.^{10–13} Lower SES is associated with SHS and is a major driver of increased BMI. Differences in exercise frequency and screen time could be associated with the opportunity for SHS in the home in addition to the risk of obesity. All covariates used data of the participants when they were in the 4th grade.

Annual household income was categorized into four groups (<JPY 3 million (approximately USD27,000), JPY 3–6 million (USD27,000–54,500), JPY 6–10 million (USD54,500–90,900), \geq JPY 10 million (USD90,900)) based on the previous study.³² Mother's education was categorized into four groups (junior high school/high school, technical/junior college/college dropout, college/graduate school, others/missing). Mother's age was categorized into three groups (<30 years, 30–39 years, \geq 40 years)

Family history of obesity was classified as "Yes" if the mother or father was obese and "No" if the mother and father were not obese. Maternal or paternal obesity was defined as a BMI of 25 kg/m² or greater³³ for the mother or father when the child was in the 4th grade. Child BMI in 4th grade was categorized into three groups (<1 SD, 1–2 SD, \geq 2 SD). Physical activity habit was assessed by the question: "How often do you exercise for more than 1 h per week?" The response to the question was "rarely or never," "1–2 times/week," "3–4 times/week," "5–6 times/week" and " \geq 7 times/week." We collapsed the four categories into three (\geq 3 times/week, 1–2 times/week, <1 time/week) based on the physical activity guidelines.³⁴ The habit of drinking sugar-sweetened beverages was assessed by the question: "How often do you drink sugar-sweetened beverages?" The response to the question was " \geq 1 time/day," "1 time/day," "4–6 times/week," "2–3 times/week," "1 time/week," and "several/month or never." We collapsed the six categories into three (\geq 1 time/day, 2–6 times/week, \leq 1 time/week). Two questions assessed screen time: "How much time do you spend watching television per day?" and "How much time do you spend using a mobile phone?" The screen time was categorized into two groups, respectively (<2 h/day, \geq 2 h/day), based on the recommendation by the American Academy of Pediatrics.³⁵ The missing data included in all covariates adjusted for regression analyses were created as new dummy variables.

Statistical analyses

Ordinal regression analysis was used to evaluate the association between changes in SHS status and the risk of being in the higher BMI category (underweight or normal weight (<–1 SD), overweight (1–2 SD), obesity (\geq 2 SD)). The parallel regression assumption was not violated by Brant's test ($p = 0.077$). We built two adjusted models in the following order: Model 1 was adjusted for SES such as annual household income and mother's education, mother's age, family history of obesity, and child BMI in 4th grade; Model 2 was further adjusted for lifestyle-related factors such as frequency of exercise, screen time, and frequency of sugar-sweetened beverage consumption.

We also evaluated the impact of the interaction between exposure to SHS and sex on the risk of being in the higher BMI category. Since the interaction term indicated a possible effect modification ($p = 0.087$), we conducted ordinal regression analyses separately for boys and girls.

Data analyses were carried out using STATA version 15 (Stata Corp LP. 2017. College Station, TX, USA).

RESULTS

Table 1 shows the characteristics of the participants; 15.2% of the participants continued SHS in 4th and 6th grade, 5.8% quit SHS

Table 1. Characteristics of participants.

SHS exposure status		Total	No SHS in 4th and 6th grades	Start SHS from 4th grade to 6th grade	Quit SHS from 4th grade to 6th grade	Continuous SHS in 4th and 6th grades
		N (%)	N (%)	N (%)	N (%)	N (%)
		3605	2672 (74.1)	174 (4.8)	210 (5.8)	549 (15.2)
BMI z-score in 6th grade	<1 SD	2696 (74.8)	2056 (76.9)	134 (77.0)	147 (70.0)	359 (65.4)
	1–2 SD	649 (18.0)	449 (16.8)	30 (17.2)	43 (20.5)	127 (23.1)
	≥2 SD	260 (7.2)	167 (6.2)	10 (5.7)	20 (9.5)	63 (11.5)
BMI z-score in 4th grade	<1 SD	2876 (79.8)	2179 (81.5)	141 (81.0)	154 (73.3)	402 (73.2)
	1–2 SD	521 (14.5)	359 (13.4)	21 (12.1)	46 (21.9)	95 (17.3)
	≥2 SD	200 (5.5)	128 (4.8)	11 (6.3)	10 (4.8)	51 (9.3)
	Missing	8 (0.2)	6 (0.2)	1 (0.6)	0 (0.0)	1 (0.2)
Sex	Boy	1801 (50.0)	1351 (50.6)	83 (47.7)	104 (49.5)	263 (47.9)
	Girl	1804 (50.0)	1321 (49.4)	91 (52.3)	106 (50.5)	286 (52.1)
	Missing	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
Annual household income (million yen)	<3	350 (9.7)	207 (7.7)	23 (13.2)	21 (10.0)	99 (18.0)
	3–6	1067 (29.6)	747 (28.0)	51 (29.3)	64 (30.5)	205 (37.3)
	6–10	1259 (34.9)	1010 (37.8)	57 (32.8)	74 (35.2)	118 (21.5)
	≥10	450 (12.5)	369 (13.8)	18 (10.3)	21 (10.0)	42 (7.7)
	Unknown/missing	479 (13.3)	339 (12.7)	25 (14.4)	30 (14.3)	85 (15.5)
Mother's education	Junior high school/high school	1050 (29.1)	665 (24.9)	59 (33.9)	76 (36.2)	250 (45.5)
	Technical/junior college/college dropout	1297 (36.0)	1042 (39.0)	63 (36.2)	65 (31.0)	127 (23.1)
	Collage/graduate school	635 (17.6)	547 (20.5)	19 (10.9)	31 (14.8)	38 (6.9)
	Other/missing	623 (17.3)	418 (15.6)	33 (19.0)	38 (18.1)	134 (24.4)
Mother's age (years)	<30	38 (1.1)	12 (0.4)	4 (2.3)	3 (1.4)	19 (3.5)
	30–39	1210 (33.6)	841 (31.5)	81 (46.6)	66 (31.4)	222 (40.4)
	≥40	2264 (62.8)	1749 (65.5)	86 (49.4)	137 (65.2)	292 (53.2)
	Missing	93 (2.6)	70 (2.6)	3 (1.7)	4 (1.9)	16 (2.9)
Family history of obesity	No	1740 (48.3)	1336 (50.0)	84 (48.3)	89 (42.4)	231 (42.1)
	Yes	1177 (32.6)	855 (32.0)	60 (34.5)	87 (41.4)	175 (31.9)
	Missing	688 (19.1)	481 (18.0)	30 (17.2)	34 (16.2)	143 (26.0)
Frequency of exercise	Never/rarely	399 (11.1)	277 (10.4)	11 (6.3)	29 (13.8)	82 (14.9)
	1–2 times/week	1351 (37.5)	1029 (38.5)	67 (38.5)	82 (39.0)	173 (31.5)
	≥3 times/week	1840 (51.0)	1360 (50.9)	95 (54.6)	99 (47.1)	286 (52.1)
	Missing	15 (0.4)	6 (0.2)	1 (0.6)	0 (0.0)	8 (1.5)
Watching television	<2 h/day	2237 (62.1)	1699 (63.6)	112 (64.4)	115 (54.8)	311 (56.6)
	≥2 h/day	1278 (35.5)	913 (34.2)	58 (33.3)	89 (42.4)	218 (39.7)
	Missing	90 (2.5)	60 (2.2)	4 (2.3)	6 (2.9)	20 (3.6)
Using mobile phone	<2 h/day	2979 (82.6)	2286 (85.6)	128 (73.6)	160 (76.2)	405 (73.8)
	≥2 h/day	601 (16.7)	369 (13.8)	46 (26.4)	47 (22.4)	139 (25.3)
	Missing	25 (0.7)	17 (0.6)	0 (0.0)	3 (1.4)	5 (0.9)
Frequency of sugar-sweetened beverages consumption	≤1 time/week	1316 (36.5)	1010 (37.8)	58 (33.3)	66 (31.4)	182 (33.2)
	2–6 times/week	1452 (40.3)	1092 (40.9)	72 (41.4)	84 (40.0)	204 (37.2)
	≥1 time/day	804 (22.3)	546 (20.4)	44 (25.3)	59 (28.1)	155 (28.2)
	Missing	33 (0.9)	24 (0.9)	0 (0.0)	1 (0.5)	8 (1.5)

from 4th to 6th grade, 4.8% started SHS from 4th to 6th grade, and 74.1% were not exposed to SHS in 4th and 6th grade. In 6th grade, 18.0% had BMI between 1 and 2 SD, and 7.2% had BMI over 2 SD. In 4th grade, 14.5% had BMI between 1 and 2 SD, and 5.5% had BMI over 2 SD. In 6th graders, the proportion of those with 1–2 SD and those with 2 SD or more increased compared to 4th graders. The proportion of boys and girls was similar. The continuous SHS group was likely to have lower household income, mother's education, and mother's age.

Table 2 shows the association between change in SHS status and the risk of being in the higher BMI category by ordinal logistic regression analyses. The continuous SHS group showed a significantly higher risk of being in the high BMI category compared to the no SHS group (odds ratio (OR) = 1.79, 95% confidence interval (CI) 1.47–2.17) (Crude model). After adjusting for BMI z-score in 4th grade, sex, annual household income, mother's education, mother's age, family history of obesity, the risk of being in the higher BMI category was mildly attenuated but still significantly higher (OR = 1.51, 95% CI 1.17–1.95) (Model 1). This association remained significant even after further adjusting for lifestyle habits in 4th grade, such as frequency of exercise, watching television, using a mobile phone, and frequency of sugar-sweetened beverage consumption (OR = 1.51, 95% CI 1.16–1.96) (Model 2). On the other hand, the quit SHS group did not show a higher risk of being in the high BMI category compared to the no SHS group after adjusting for the covariates (OR = 1.11, 95% CI 0.75–1.66). The start SHS group did not show a higher risk of being in the high BMI category compared to the no SHS group after adjusting for the covariates (OR = 0.90, 95% CI 0.57–1.45). The risk of having a high BMI category in the continuous SHS group was high (OR = 1.36, 95% CI 0.87–2.12) when the quit SHS group was used as a reference (data not shown).

Table 3 shows the association between change in SHS status and the risk of being in the higher BMI category by ordinal logistic regression analyses stratified by sex. The stratified analyses by sex showed a similar association of increased risk of being in the higher BMI category in the continuous SHS group compared to the no passive smoking group in boys (OR = 1.74, 95% CI 1.25–2.44) but not in girls (OR = 1.14, 95% CI 0.74–1.76). The stratified analysis also showed that the quit SHS group did not have a higher risk of being in the high BMI category in boys (OR = 1.46, 95% CI 0.88–2.41). Since we analyzed "frequently", "sometimes", and "rarely" combined into one category, boys may have a higher frequency of SHS than girls when evaluated by each frequency category. Therefore, we confirmed no sex differences in these four frequency categories in either the 4th or 6th grade (data not shown).

DISCUSSION

In the present study, we evaluated the impact of exposure to SHS on the risk of being in the higher BMI category in early adolescence. We found that continuous SHS was associated with the risk of being in the higher BMI category in the 6th grade, but quitting SHS was not associated with the risk of being in the higher BMI category, suggesting that quitting SHS from 4th grade to 6th grade may prevent obesity of children. The stratified analyses by sex showed a similar association in boys but not in girls.

Our finding of continuous SHS being associated with obesity risk in children is consistent with previous studies.^{8–12} In addition, our results suggest that quitting SHS may reduce the risk of obesity in children, especially boys. Previously, Raum et al. reported the association between SHS status at age 1–6 and overweight at age 6,¹¹ but unlike our findings, the quit SHS group at age 6 had a significantly increased risk of being overweight than those with no SHS at both ages. This association remained

significant even after adjusting for maternal smoking status before and during pregnancy. There are two possible pathways why the risk of obesity did not increase with quitting SHS. The first is that quitting SHS may prevent weight gain. Irigaray et al. reported that catecholamine-induced lipolysis in mouse adipocytes and isolated human adipocytes was inhibited by B[a]P, a polycyclic aromatic hydrocarbon (PAH) that is abundant in SHS.²¹ Chronic administration of B[a]P to mice decreased the lipolytic response induced by epinephrine and increased body weight gain by 43% due to increased fat mass than the control group.²² In addition, it was reported that plasma B[a]P levels correlated with BMI,³⁶ and PAH metabolites are associated with increased BMI, waist circumference, and obesity in children.^{37,38} Thus, chronic exposure to SHS could impact obesity, and quitting SHS may have improved the risk of obesity. The second pathway is that other risk factors for obesity, such as exercise, diet, and screen time, may have improved along with SHS improvement. Although we did not find that the quit SHS group had an increase in the frequency of exercise, decrease in screen time, and decrease in the frequency of sugar-sweetened beverages consumption compared to the continuous SHS group, the assessment of lifestyle may not be captured by the questionnaire.

The present study also showed the interaction between exposure to SHS and sex on the risk of obesity, unlike the results of previous studies.^{8,9,39} The sex difference in SHS exposure and risk of obesity may be related to the Trp64Arg polymorphism in ADRB3. ADRB3 is a key receptor related to catecholamine-induced lipolysis, and the Trp64Arg polymorphism has been reported to be associated with BMI²⁴ by decreasing thermogenesis and basal energy expenditure, and decreasing lipolysis in both white and brown adipose tissue.⁴⁰ There are several reports of sex differences in the association between Trp64Arg polymorphism and obesity, and those results are not consistent.^{40–44} The Turkish and French studies reported that the Trp64Arg mutation was associated with obesity only in women,^{41,42} while the Australian and Spanish studies reported that it was associated only with men.^{40,43} In Japan, Takeuchi et al. reported that the Trp64Arg mutation was associated with annual BMI gain only in men.⁴⁴ Since ADRB3 is found mainly in deep visceral adipocytes,⁴⁰ and boys have more visceral fat mass than girls,⁴⁵ the effect of the Trp64Arg mutation on body weight may be more significant in boys. Furthermore, the Japanese have a high frequency of Arg allele of ADRB3 gene Trp64Arg polymorphism (19%).⁴⁶ Thus, considering that inhibition of lipolysis related to ADRB3 could be one of the mechanisms affecting the relationship between SHS and body weight, the effect of the Trp64Arg polymorphism on BMI by sex may be one of the mechanisms for the sex difference.

Our study suggested that quitting SHS from 4th to 6th grade may reduce the risk of obesity in early adolescence compared to continuous SHS. Since early adolescence could be a critical period related to future obesity,¹⁶ SHS control may be considered one of the possible modifiable factors against childhood obesity. However, the generalizability of our findings should be interpreted with caution because sex interaction may differ by race. Further evaluation by sex needs to be done in other races. In addition, it is necessary to evaluate the impact of quitting SHS on obesity in other races and age groups to accumulate evidence of SHS.

In the COVID-19 pandemic, there is concern that SHS exposure will continue to be high. On the other hand, some people may try to quit smoking during this period.^{17,18} Governments and health organizations need to encourage people to quit smoking. Even in cases where smoking cessation is difficult, it is necessary to inform people of the dangers of SHS and advise them to have in place a separate area for smoking in their homes.

Several limitations of this study should be acknowledged. First, exposure to SHS was not assessed by objective measures such as cotinine concentration, a primary metabolite of nicotine.⁴⁷ However, similar questions regarding SHS were validated by

Table 2. Association between change in SHS status and the risk of being in the higher BMI category.

		Crude		Model 1		Model 2	
		OR	95% CI	OR	95% CI	OR	95% CI
Change in SHS status	No SHS in 4th and 6th grades	Ref.		Ref.		Ref.	
	Start SHS from 4th grade to 6th grade	0.99	(0.69, 1.42)	0.90	(0.56, 1.42)	0.90	(0.57, 1.45)
	Quit SHS from 4th grade to 6th grade	1.45	(1.07, 1.96)	1.11	(0.74, 1.64)	1.11	(0.75, 1.66)
	Continuous SHS in 4th and 6th grades	1.79	(1.47, 2.17)	1.51	(1.17, 1.95)	1.51	(1.16, 1.96)
BMI z-score in 4th grade	<1 SD			Ref.		Ref.	
	1–2 SD			33.42	(26.32, 42.54)	33.82	(26.53, 43.11)
	≥1 SD			422.85	(277.43, 644.49)	429.07	(280.49, 656.34)
Sex	Boy			Ref.		Ref.	
	Girl			0.36	(0.30, 0.44)	0.35	(0.29, 0.43)
Annual household income (million yen)	<3			Ref.		Ref.	
	3–6			0.96	(0.68, 1.37)	0.97	(0.68, 1.39)
	6–10			1.23	(0.86, 1.77)	1.25	(0.87, 1.80)
	≥10			1.16	(0.76, 1.78)	1.18	(0.77, 1.81)
Mother's education	Junior high school/high school			Ref.		Ref.	
	Technical/junior college/college dropout			0.88	(0.69, 1.12)	0.88	(0.69, 1.12)
	Collage/graduate school			0.90	(0.66, 1.21)	0.91	(0.67, 1.23)
	Other/missing			0.86	(0.65, 1.15)	0.87	(0.65, 1.15)
Mother's age (years)	<30			Ref.		Ref.	
	30–39			0.54	(0.25, 1.17)	0.55	(0.26, 1.20)
	≥40			0.46	(0.22, 0.99)	0.47	(0.22, 1.02)
Family history of obesity	No			Ref.		Ref.	
	Yes			2.06	(1.66, 2.55)	2.08	(1.68, 2.58)
Frequency of exercise	Never/rarely					1.13	(0.83, 1.55)
	1–2 times/week					1.17	(0.95, 1.44)
	≥3 times/week					Ref.	
Watching television	<2 h/day					Ref.	
	≥2 h/day					1.02	(0.83, 1.25)
Using mobile phone	<2 h/day					Ref.	
	≥2 h/day					0.91	(0.71, 1.17)
Frequency of sugar-sweetened beverages consumption	Never/rarely					Ref.	
	1–2 times/week					0.96	(0.77, 1.20)
	≥3 times/week					0.86	(0.67, 1.12)

Values are odds ratio (OR) and 95% confidence interval (CI) from ordinal logistic regression models for the risk of being in the higher BMI category for each SHS status compared to the reference group, no SHS in 4th and 6th grades.

Model 1: adjusted for BMI z-score in 4th grade, sex, annual household income, mother's education, mother's age, family history of obesity.

Model 2: Model 1 + further adjusted for frequency of exercise, watching television, using mobile phone, frequency of sugar-sweetened beverages consumption.

urinary cotinine levels in a previous study in Japan.³¹ Therefore, although the measure of SHS was not the same, we believe that the present questionnaire can be used as a marker of SHS exposure. Second, individuals may have had different understandings of the options for SHS frequency, as we did not provide specific explanations. However, since the SHS categories were divided into "not exposed to SHS" and "exposed to SHS", it would be unlikely that there are many misclassifications. Third, even if

the frequency of SHS was in the same category, the exposure intensity may have differed by sex because girls may engage in more SHS avoidance behaviors than boys. Fourth, information on the duration of exposure and past exposure to SHS was not collected. Some parents may have smoked in front of their children in the past, but not during the study period. In addition, we could not measure maternal smoking during pregnancy. Many studies have reported that maternal smoking during pregnancy

Table 3. Association between change in SHS status and the risk of being in the higher BMI category stratified by sex.

		Crude		Model 1		Model 2	
		OR	95% CI	OR	95% CI	OR	95% CI
Boys (n = 1801)							
Change in SHS status	No SHS in 4th and 6th grades	Ref.		Ref.		Ref.	
	Start SHS from 4th grade to 6th grade	0.97	(0.60, 1.58)	1.07	(0.59, 1.95)	1.15	(0.62, 2.11)
	Quit SHS from 4th grade to 6th grade	1.66	(1.11, 2.47)	1.39	(0.84, 2.28)	1.46	(0.88, 2.41)
	Continuous SHS in 4th and 6th grades	2.29	(1.77, 2.95)	1.71	(1.23, 2.38)	1.74	(1.25, 2.44)
Girls (n = 1804)							
Change in SHS status	No SHS in 4th and 6th grades	Ref.		Ref.		Ref.	
	Start SHS from 4th grade to 6th grade	1.08	(0.62, 1.88)	0.67	(0.32, 1.40)	0.67	(0.32, 1.42)
	Quit SHS from 4th grade to 6th grade	1.25	(0.76, 2.06)	0.76	(0.39, 1.46)	0.73	(0.38, 1.42)
	Continuous SHS in 4th and 6th grades	1.37	(1.00, 1.89)	1.18	(0.77, 1.79)	1.14	(0.74, 1.76)

Values are odds ratio (OR) and 95% confidence interval (CI) from ordinal logistic regression models for the risk of being in the higher BMI category for each SHS status compared to the reference group, no SHS in 4th and 6th grades, for boys and girls, respectively.

Model 1: adjusted for BMI z-score in 4th grade, sex, annual household income, mother's education, mother's age, family history of obesity.

Model 2: Model 1 + further adjusted for frequency of exercise, watching television, using mobile phone, frequency of sugar-sweetened beverages consumption.

was associated with childhood obesity.⁴⁸ Therefore, in children whose mothers have been smoking since pregnancy, the effect of SHS on obesity risk may be overestimated. However, it is noteworthy that some studies reported that SHS was associated with childhood obesity even after adjusting for maternal smoking during pregnancy.^{9,11} Fifth, we were unable to assess the children's active smoking. However, in Japan, the percentage of habitual smokers among primary school students is extremely low (0.04–0.1%).^{49,50} The impact on our results would be small. Sixth, BMI is the most widely reported practical and reproducible measure, but it does not necessarily reflect fat mass. A similar assessment with body fat percentage and visceral fat will be needed in the future. Finally, because of the relatively short time frame for assessing the impact of changes in SHS status, lifestyle changes from 4th to 6th grade may have affected the results as residual confounders, although we adjusted for the lifestyle habits in 4th grade. The change in lifestyle related to obesity, such as exercise, diet, and screen time, is expected to be considerable due to the COVID-19 pandemic. However, we confirmed that the change in SHS status was not associated with the change in those lifestyle habits. For example, the quit SHS group did not increase the frequency of exercise, decrease screen time, and decrease the frequency of sugar-sweetened beverages consumption compared to the continuous SHS group (data not shown).

In conclusion, continuous SHS was a risk factor for obesity in boys in early adolescence. However, quitting SHS may help to prevent it. Further study is needed to confirm the preventive effect of quitting SHS on obesity risk and examine sex differences in obesity risk by exposure to SHS.

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AUTHOR CONTRIBUTIONS

T.F. conceived the study. T.F., M.O., A.I., and S.D. conducted the survey and collected data. K.M. was primarily responsible for data analysis and wrote the first draft of the paper. N.N. and T.F. helped draft, review, and revise the manuscript. All authors approved the final manuscript to be published and agree to be accountable for all aspects of the work.

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COMPETING INTERESTS

The authors declare no competing interests.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

The study was approved by the Ethics Committees at the National Center for Child Health and Development (Study ID: 1147) and Tokyo Medical and Dental University (Study ID: M2016–284). All participants gave informed consent to participate in the survey.

ADDITIONAL INFORMATION

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