ORIGINAL RESEARCH

Influence of the consumption of sugary drinks and sleep duration on the association of Internet use and dental caries among 12–19 years old adolescents in Xiamen city, China

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Abstract

Background: This study investigated the prevalence of dental caries among adolescents aged 12–19 years in Xiamen, China and evaluated its association with Internet usage time. The mediation effect of sugary drinks consumption and sleep duration on the association between dental caries and Internet usage time was also examined. **Methods**: We recruited 11,361 adolescents using multistage stratified random sampling method in Xiamen. Dental caries assessment was conducted by professional dentists under natural light using disposable mouth mirrors and dental probes, following the World Health Organization (WHO) guidelines. Dental caries was evaluated with the sum of decayed, missing, and filled permanent teeth (DMFT) index. The information about demographic characteristics and lifestyle behaviors was collected by self-administered questionnaire. The association between Internet usage time and dental caries was analyzed using binary logistic regression. The mediation effect of sugary drinks consumption and sleep duration on the association was assessed using mediation analysis. **Results**: The overall prevalence of dental caries among adolescents aged 12–19 years in Xiamen was 56.9%, which varied among sex, age, residence, and body mass index (BMI) ($p < 0.001$). Longer Internet usage time (adjusted odds ratios (AOR): 1.16; 95% confidence interval (95% CI): 1.02–1.32) was associated with a higher risk of dental caries. Moreover, higher sugary drinks consumption and insufficient sleep increased the risk of dental caries (sugary drinks: AOR: 1.54; 95% CI: 1.28–1.82; sleep duration: AOR: 1.23; 95% CI: 1.10–1.37). The frequency of sugary drinks consumption and sleep duration mediated the association between Internet usage time and dental caries by 13.89% and 5.56%, respectively. **Conclusions**: Adolescents aged 12–19 years-old in Xiamen had a high prevalence of dental caries, which was significantly associated with Internet usage time. The association between dental caries and Interne usage time was mediated by the frequency of sugary drink consumption and sleep duration.

Keywords

Adolescents; Eating behavior; Sleep duration; Internet use; Dental caries

1. Introduction

Dental caries is an outcome of demineralization of dental hard tissues by organic acids produced by the interaction between acid-producing bacteria and fermentable carbohydrates in the oral cavity [1]. Globally, dental caries affects 500 million adolescents' oral health [2]. The prevalence of dental caries among Chinese adolescents was 41.9% in 2015 [3]. If left untreated early, dental caries can deteriorate and lead to toothache, functional limitations, and tooth loss [4]. It affects the growth and development of adolescents and imposes family economic burden [5, 6].

The occurrence of dental caries is influenced by many fac-tors, such as sociodemographic factors, family's socioeco-nomic status, and individual lifestyle [7]. Sadjadpour *et al*. [8] reported that girls, older adolescents, those living in rural areas, and those with lower body mass index (BMI) had higher prevalence of dental caries. Adolescents from families with low socioeconomic status have poorer oral hygiene habits and an increased risk of dental caries than those from families with higher socioeconomic status [9]. Besides, unhealthy behaviors, such as lower frequency of tooth brushing, higher consumption of sugary drinks, and insufficient sleep, were also found to be associated with a higher prevalence of dental caries Su *et al*. [10] found the prevalence of dental caries among adolescents who brushed teeth twice a day to be 15.3% lower

than that of those who brushed once a day. The prevalence of dental caries of adolescents who consumed two or more sugary drinks per day was 15.3% higher than that of those who never consumed [11]. The incidence of dental caries among adolescents increased by 30% for each additional hour delayed in bedtime [12].

Internet has become a crucial tool for adolescents to obtain information and entertainment in their daily lives. By now, China's Internet usage rate among adolescents aged 6–18 years was reported to be 95% [13]. When adolescents spend long time on the Internet, they are more likely to have longer sitting time and consume more unhealthy foods and drinks [14]. Gu *et al*. [15] found that adolescents who spent four hours per day on the Internet were 1.46 times more likely to consume sugary drinks than those who did not use the Internet. Higher consumption of sugary drinks results in increased acid production from fermentation on tooth surface, and significantly increases the risk of dental caries [16]. Moreover, adolescents with excessive Internet use had shorter sleep duration [17]. Inadequate sleep can diminish immune function and reduce salivary flow, and increase the risk of dental caries [18]. A cross-sectional study in Japan indicated that sleep duration was negatively associated with the numbers of caries lesions in preschoolers [19].

As a preventable disease, early identification of risk factors of dental caries and implementation of preventive measures can reduce or even avoid its occurrence. Understanding the prevalence of dental caries and potential influencing factors is beneficial for governments and schools to implement effective prevention strategies and reduce the incidence of dental caries. By now, epidemiological data on the prevalence of dental caries among adolescents in Xiamen were not available. This study aimed to investigate the prevalence of dental caries among adolescents aged 12–19 in Xiamen city and its association with Internet usage time. Excessive use of Internet may increase unhealthy behaviors including high consumption of sugary drinks and insufficient sleep. We hypothesized that sugary drink consumption and sleep duration may mediate the association between Internet usage time and dental caries.

2. Method

2.1 Study design and setting

This study was a cross-sectional investigation of the oral health status of adolescent students in Xiamen from June 2020 to December 2022, which was part of the national monitoring project on common diseases and health influencing factors of students in Xiamen. Ethical approval was obtained from the Ethics Committee of Xiamen Center for Disease Control and Prevention through the quick review process during the COVID-19 pandemic with verbal confirmation prior to data collection. The formal ethical approval (XJK/LLSC2023007) was issued in August 2023. The study was conducted in accordance with the Declaration of Helsinki and reported following the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines.

2.2 Study participants

Participants were recruited using a multistage stratified random sampling based on the population proportion. In urban district, five schools were randomly selected including two junior high schools, two senior high schools, and one vocational senior middle school. In suburban district, three schools were randomly selected including two junior high schools and one senior high school. In each selected school, two classes from each grade were randomly selected using cluster sampling method. All students in the selected classes were included in the study. A minimum of 80 students from each grade were selected for physical examination and questionnaire surveys.

The sample size was calculated based on the prevalence of dental caries among adolescents aged 12–15 years reported by the Fourth National Oral Health survey in China, which was about 41.9% [3]. The permissible relative error of the overall *p* value was controlled by 10%, design effect (*deff*) = 4, and α = 0.05. According to the formula of $n = deff \frac{u_\alpha^2 p(1-p)}{\delta^2}$, the sample size for this study was at least 2131.

2.3 Inclusion and exclusion criteria

Adolescents aged 12 to 19 years, residing in Xiamen city for more than 6 months, were eligible to participate. The age range represents an important period of dental development, including the eruption of permanent teeth and the transition from primary to permanent dentition. Newly erupted permanent teeth have thinner enamel, and hormonal fluctuations during puberty may disrupt the stability of the oral environment, making the teeth more susceptible to plaque accumulation, thereby increasing the risk of permanent dental caries. Furthermore, the independent sense of adolescents gradually increases with age while parental supervision gradually weakens. As a result, they are more likely to consume sugary drinks and go to bed late, both of which contribute to a higher risk of developing dental caries. Individuals with systemic autoimmune diseases or mental disorders were excluded.

In total, 13,345 adolescents were recruited for the study, in which 1718 parents did not agree to participate, and 266 students had incomplete and illogical data. The remaining 11,361 students were included in final analysis, with a response rate of 85.13%. All adolescents participating in the investigation and their parents or guardians were informed of the purpose and procedure of the study and signed informed consent forms.

2.4 Clinical examination of dental caries

The clinical examination of dental caries was conducted by three professional dentists under natural light using disposable intraoral mouth mirrors and dental probes. The dentists cleaned and dried the surface of teeth using a sterile gauze before examination. The points, gaps, pits, grooves, and other areas of the tooth that are prone to caries were examined. Caries status was assessed using the sum of decayed, missing, and filled permanent teeth (DMFT) index according to the World Health Organization's (WHO) oral health survey guidelines (2013) [20]. The DMFT index higher than zero indicates the presence of caries (coded as 1), whereas a zero score indicates the absence of caries (coded as 0). All the dentists

received training to establish standardized criteria for diagnosis before the study. After the examination, we randomly selected 5% of participants for re-examination and calculated the Kappa value to evaluate the agreement of examination results among dentists. The results showed high inter-examiner reliability with a Kappa value of 0.83.

2.5 Anthropometrical measurement

Anthropometric indices, including weight and height, are commonly investigated in oral health studies since it can reflect the nutritional status of participants. Individuals with underweight may experience malnutrition, which could impair salivary gland function, leading to reduced salivary flow and buffering capacity, thereby increasing the risk of dental caries. Therefore, we assessed the height and weight to examine the association between adolescent's nutritional status and dental caries. Height and weight were assessed by well-trained investigators using standardized techniques and procedures. Adolescents' height and weight were measured using a digital scale and a stadiometer with error at 0.1 cm and 0.1 kg. Body mass index (BMI) was calculated by dividing body weight in kilograms by height in meters squared. Adolescents were categorized as underweight, normal weight, overweight, or obesity [21, 22].

2.6 Questionnaire survey

A standard questionnaire, designed by the Chinese Center for Disease Control and Prevention, was used to collect information on demographic characteristics and lifestyle habits [23]. Demographic characteristics included age, sex, and residence, while lifestyle factors included dietary habit, tooth brushing habit, sleep duration, and Internet usage time. The question on dietary habit was as follows: "what is the intake frequency of sugary drinks/fried food/vegetable/fruit in the past week?". Response options included: 1 = "never drink/eat", 2 = "<1 time/d", and 3 = "≥1 time/d". Adolescent's tooth brushing habit was assessed using the following question: "What is your tooth brushing frequency a day?", with possible responses including: 1 = "twice a day" and 2 = "less than twice a day". Internet usage time was obtained through the question: "How many hours per day did you use the Internet on smartphone, computer, and tablet?", with response options as follows: 1 = "<1 h", 2 = "1–3 h", and 3 = ">3 h" [13]. The question of sleep duration was asked as: "How many hours of sleep do you have every night?". The answers were coded as 1 = "<8 h" and 2 = "≥8 h" [24]. All students completed the questionnaire under the supervision of a research assistant.

2.7 Analytical methodology

Data were analyzed with IBM SPSS Statistics 26.0 (IBM Corp., Armonk, NY, USA). Continuous variables were expressed by mean ± standard deviation (SD) and categorical variables were summarized by numbers and frequencies. Chi-square tests were used to compare differences in the prevalence of caries among adolescents with different characteristics. Non-parametric tests, including Mann-Whitney U or Kruskal-Wallis H test, were used to compare differences in the DMFT index among adolescents with different characteristics. Binary logistic regression was employed to screen factors, and those with a significance level below 0.1 were subsequently included in multivariable logistic regression to further assess the relationships between lifestyle factors and dental caries [25].

The mediation analysis utilized Version 3.3 of the PROCESS macro software on SPSS 26.0 to explore the mediating influence of sugary drink and sleep duration on the association between Internet usage time and dental caries. Mediation occurs when an independent variable (X) influences a dependent variable (Y) through one or more mediators (M). Path a is used to represent the impact of X on M, path b is used to represent the impact of M on Y after controlling for the effect of X, path c' represents the direct effect of X on Y. The indirect effect of X on Y through M is the product of a and b (*i.e.*, a × b). The total effect is equal to the sum of the indirect and direct effects (*i.e.*, c = a × b + c' for single mediator model, $c = a_1 \times b_1 + a_2 \times b_2 + c'$ for two multiple mediator model). The mediated (indirect) effect was analyzed using a non-parametric bootstrapping procedure (n = 5000 samples) that estimated the sampling distribution of the indirect effect and the corresponding bias-corrected and accelerated 95% confidence interval (CI) [26]. When the 95% CI did not contain zero, the indirect effect was considered significant. A *p*-value less than 0.05 was considered statistically significant.

3. Results

3.1 General characteristics of participants

The adolescents aged from 12 to 19 years, 5804 (51.09%) were boys, and 7801 (68.66%) resided in urban areas. Additionally, 809 (7.1%) adolescents had sugary drinks more than once a day, 9616 (84.6%) adolescents slept less than 8 hours a day, and 1201 (10.6%) spent more than 3 hours a day on Internet.

3.2 Prevalence of dental caries

As shown in Table 1, the overall prevalence of caries was 56.9%, which was higher among girls (63.9%) and increased with age. The overweight and obese adolescents had a lower prevalence (52.7% and 51.5%) than those with normal weight (59.0%). Those living in suburban areas had a higher prevalence (72.8%). Furthermore, adolescents with a higher frequency of sugary drinks consumption, longer Internet usage time and less sleep duration exhibited higher prevalence of dental caries (59.0%, 59.6% and 57.5%, respectively).

3.3 Multivariable logistic regression for dental caries

As shown in Table 2, sex, age, residence, BMI, frequency of sugary drinks, sleep duration, and Internet usage time were all correlated with the occurrence of dental caries. On multivariable logistic regression analysis, the risk of dental caries of girls was 1.70 times (95% CI: 1.57–1.84) as much as boys. The adjusted odds ratios (AOR) of dental caries increased with age. The risk of adolescents from suburban areas was 2.94 times (95% CI: 2.69–3.21) as much as the risk of those from urban

T A B L E 1. Descriptive analysis for prevalence of dental caries and characteristics among 12–19 adolescents.

Characteristics	Number of participants (N)	Prevalence of dental caries		χ^2 value	p value	DMFT index (Mean ± SD)	Z/H	p value
		n	%					
Total	11,361	6469	56.9	-	-	1.87 ± 2.29	-	-
Sex								
Boy	5804	2922	50.3	212.84	<0.001	1.47 ± 2.04	−18.88	<0.001
Girl	5557	3551	63.9			2.29 ± 2.45		
Age (yr)								
12–15	5064	2747	54.2			1.62 ± 2.08		
15–17	3900	2300	59.0	27.94	<0.001	2.05 ± 2.41	79.81	<0.001
17–19	2397	1426	59.5			2.12 ± 2.45		
BMI								
Underweight	1591	898	56.4			1.77 ± 2.18		
Normal	6926	4088	59.0			1.97 ± 2.32		
Overweight	1746	921	52.7	37.96	<0.001	1.72 ± 2.23	40.07	<0.001
Obese	1098	566	51.5			1.65 ± 2.21		
Residence								
Urban	7801	3883	49.8	526.47	<0.001	1.46 ± 2.01	−28.31	<0.001
Suburban	3560	2590	72.8			2.79 ± 2.57		
Sugary drinks								
Never	2327	1253	53.8			1.78 ± 2.30		
<1 time/d	8225	4743	57.7	12.20	0.002	1.89 ± 2.27	11.24	0.004
≥1 time/d	809	477	59.0			1.98 ± 2.35		
Fried food								
Never	1682	934	55.5			1.81 ± 2.28		
<1 time/d	9008	5138	57.0	3.58	0.167	1.88 ± 2.28	4.76	0.093
≥1 time/d	671	401	59.8			2.02 ± 2.36		
Vegetables								
Never	185	115	62.2			2.39 ± 2.58		
<1 time/d	980	588	60.0	6.30	0.043	2.06 ± 2.38	13.91	0.001
≥1 time/d	10,196	5770	56.6			1.85 ± 2.27		
Fruit								
Never	396	231	58.3			2.05 ± 2.40		
<1 time/d	3689	2122	57.5	1.11	0.573	1.97 ± 2.37	8.03	0.018
≥1 time/d	7276	4120	56.6			1.81 ± 2.23		
Tooth brushing								
≤2 times/d	2766	1507	54.5	9.27	0.002	1.72 ± 2.19	−3.92	<0.001
>2 times/d	8595	4966	57.8			1.92 ± 2.31		
Internet usage time								
<1 h	6851	3810	55.6			1.79 ± 2.24		
1–3 h	3309	1947	58.8	13.30	0.001	1.99 ± 2.33	24.11	<0.001
>3 h	1201	716	59.6			2.05 ± 2.37		
Sleep duration								
≥8 h	1745	941	53.9	7.82	0.005	1.67 ± 2.15	−3.716	<0.001
<8 h	9616	5532	57.5			1.91 ± 2.30		

DMFT: decayed, missing, and filled permanent teeth; SD: standard deviation; BMI: body mass index.

TABLE 2. Multiple-factor binary logistic regression analyses of factors associated with dental caries (DMFT >0) for individuals aged 12–19 in Xiamen city.

Variable	OR	95% CI	*p* value	Adjusted OR	95% CI	*p* value
Sex (Ref: boy)						
Girl	1.75	1.62–1.89	<0.001	1.70	1.57–1.84	<0.001
Age (yr) (Ref: 12–15)						
15–17	1.21	1.11–1.32	<0.001	1.44	1.31–1.57	<0.001
17–19	1.24	1.12–1.37	<0.001	1.51	1.37–1.68	<0.001
BMI (Ref: normal)						
Underweight	0.90	0.81–1.00	0.060	1.01	0.90–1.13	0.898
Overweight	0.78	0.70–0.86	<0.001	0.82	0.73–0.91	<0.001
Obese	0.74	0.65–0.84	<0.001	0.80	0.70–0.92	<0.001
Residence (Ref: urban)						
Suburban	2.69	2.47–2.94	<0.001	2.94	2.69–3.21	<0.001
Sugary drinks (Ref: never)						
<1 time/d	1.17	1.06–1.28	0.001	1.24	1.13–1.35	<0.001
≥1 time/d	1.23	1.04–1.45	0.012	1.54	1.28–1.82	<0.001
Tooth brushing (Ref: ≤2 times/d)						
2 times/d	1.14	1.05–1.25	0.002	1.03	0.94–1.13	0.490
Internet usage time (Ref: <1 h)						
1–3 h	1.14	1.05–1.24	0.002	1.07	0.98–1.17	0.110
>3 h	1.18	1.04–1.34	0.010	1.16	1.02–1.32	0.029
Sleep duration (Ref: ≥8 h)						
<8 h	1.16	1.05–1.28	0.005	1.23	1.10–1.37	<0.001

OR: odds ratio; CI: confidence interval; BMI: body mass index.

areas. The overweight (AOR: 0.82; 95% CI: 0.73–0.91) and obese (AOR: 0.80; 95% CI: 0.70–0.92) adolescents were less likely to suffer from dental caries. Adolescents who consumed sugary drinks more than once a day were 1.54 times (95% CI: 1.28–1.82) more likely to have dental caries than those who never consumed. Those who used the Internet for 3 hours or more per day had 1.16 times (95% CI: 1.02–1.32) more risk of dental caries than those who used 1 hour or less. Additionally, adolescents with less than 8 hours sleep duration had a higher risk of dental caries than those with more than 8 hours of sleep (AOR: 1.23; 95% CI: 1.10–1.37).

3.4 Mediation analyses

Table 3 presents the results of single mediator analyses on the association between dental caries and Internet usage time. There was a significant total effect (path c) of Internet usage time on dental caries. Adolescents with high Internet usage time were more likely to have dental caries (β: 0.038; 95% CI: 0.028–0.080). Internet usage time had a significant effect on sugary drinks and sleep duration (path a). Internet usage time was positively associated with sugary drinks (β: 0.042; 95% CI: 0.035–0.048) and negatively associated with sleep duration (β: −0.012; 95% CI: −0.019–−0.005). Path b showed the association between potential mediator and dental caries adjusted for Internet usage time. Sugary drinks had a positive effect on dental caries (β: 0.129; 95% CI: 0.047–0.211). Sleep

duration had a negative effect on dental caries (β: −0.212; 95% CI: −0.284–−0.140). Both of sugary drinks (β: 0.005; 95% CI: 0.002–0.009) and sleep duration (β: 0.003; 95% CI: 0.001–0.004) showed an indirect effect. The direct effect was also significant (sugary drinks: β: 0.036; 95% CI: 0.010–0.064; sleep duration: β: 0.041; 95% CI: 0.014–0.067). Therefore, the frequency of sugary drinks and sleep duration could be identified as partial mediators between Internet usage time and dental caries. The frequency of sugary drinks mediated 13.89% and sleep duration mediated 5.56% of the association between Internet usage time and dental caries (Fig. 1).
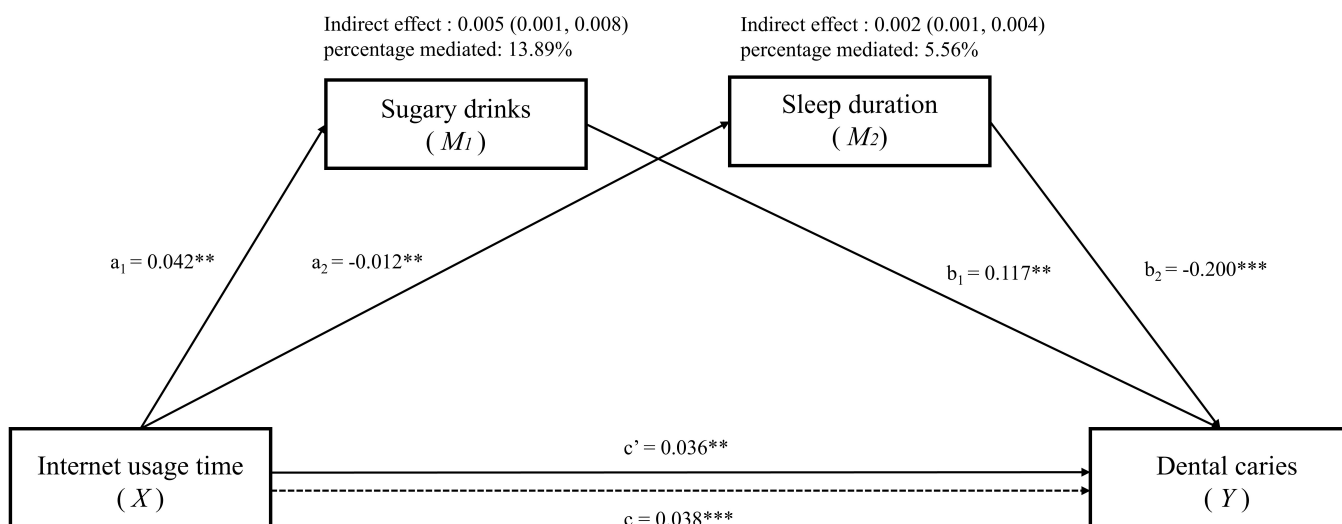
4. Discussion

The present study investigated the prevalence of dental caries and its association with Internet usage time among adolescents aged 12–19 years in Xiamen. The prevalence of dental caries among adolescents in Xiamen was 56.9%, which was higher than Zhejiang (44%) [27] and lower than the prevalence reported in Kunming (73%) [28]. The variation in age ranges may contribute to the difference in the prevalence reported in different studies. The age range of adolescents in our study was from 12 to 19 years. The study conducted in Zhejiang mainly focused on the adolescents aged 12 to 14 years, an age group with a lower prevalence of dental caries, while the Kunming study focused on adolescents aged from 17 to 19 years, an age

T A B L E 3. The single mediating effect of sugary drinks and sleep duration on the association between Internet usage time and dental caries.

	Sugary drinks			Sleep duration		
	β	95% CI	*p* value	β	95% CI	*p* value
Total effect (path c, XY)	0.038	(0.028, 0.080)	<0.001	0.038	(0.028, 0.080)	<0.001
Income effect on mediator (path a, XM)	0.042	(0.035, 0.048)	<0.001	−0.012	(−0.019, −0.005)	0.001
Mediator effect on Dental Caries (path b, MY)	0.129	(0.047, 0.211)	0.002	−0.212	(−0.284, −0.140)	<0.001
Direct effect (path c'-XY$_{adjM}$)	0.036	(0.010, 0.064)	0.006	0.041	(0.014, 0.067)	0.002
Indirect effect (a × b-XMY)	0.005	(0.002, 0.009)	0.002	0.003	(0.001, 0.004)	0.004

CI: confidence interval.

Indirect effect : 0.005 (0.001, 0.008) percentage mediated: 13.89%

Indirect effect : 0.002 (0.001, 0.004) percentage mediated: 5.56%

Sugary drinks (M_1)

Sleep duration (M_2)

$a_1 = 0.042$** $a_2 = -0.012$** $b_1 = 0.117$** $b_2 = -0.200$***

Internet usage time (X)

Dental caries (Y)

c' = 0.036**
c = 0.038***

F I G U R E 1. The mediating effect of sugary drinks and sleep duration on the association between Internet usage time and dental caries (Multiple mediator model). **$p < 0.01$, ***$p < 0.001$.

group with a higher prevalence of dental caries. As indicated above, the prevalence of dental caries increased with age [29]. It is not difficult to explain that the prevalence of dental caries in our study was between those studies.

We found that dental caries was associated with sex, age, residence area, BMI, frequency of sugary drinks, sleep duration and Internet usage time. Girls had a higher risk of dental caries than boys, which was similar to the results of Wen's study [30]. The physiological maturation of girls is generally earlier than boys, as they have earlier eruption of permanent teeth with longer exposure to oral environment, which increases the risk of dental caries [31]. This can also explain why the prevalence of dental caries increases with age, as older adolescents experience a longer time of exposure to cariogenic factors, which increases the risk of dental caries over time. Adolescents living in the suburban area had a higher prevalence than those living in the urban area. Lower oral health awareness and limited access to dental healthcare services may contribute to their higher risk of dental caries [32]. In addition, our results indicated that overweight and obese adolescents were less likely to have dental caries. Similar results have been reported in Shi's study [33]. Overweight and obese adolescents may come from economically affluent families, where parents may pay more attention to children's oral health and could provide more access to dental services.

In addition, saliva production of overweight and obese adolescents might increase with the increase of food consumption. The saliva as a mechanical cleanser and pH buffer can reduce the retention of sugars and dental plaque, providing protection to the teeth [34].

Our results indicated that adolescents consuming more sugary drinks had a higher risk of dental caries, similarly reported by Ha *et al*. [35]. Excessive consumption of sugary drinks increases the amount of fermentable carbohydrates in the oral cavity. These carbohydrates are converted into organic acids by bacteria, which decreases the oral pH and disrupts the balance of the bacterial flora in the mouth, thereby increasing the risk of tooth caries. Jocelyn *et al*. [36] found that if adolescents consume an extra cup of sugary drinks a day, their prevalence of dental caries increased by 22%.

We also found that adolescents with insufficient sleep were more likely to have dental caries, which was supported by Asaka *et al*. [37]. They found that adolescents who slept less than 8 hours were 1.49 times more likely to develop dental caries than those who slept more than 9 hours. Insufficient sleep leads to hormonal disorder, resulting in reduced leptin levels and increased ghrelin levels, which may drive adolescents to preferentially choose high-carbohydrate food and increase the risk of dental caries [38]. In addition, reduced sleep duration is associated with decreased salivary flow and

reduced salivary immunoglobulin A (S-IgA) secretion [39]. The reduction of saliva flow and S-IgA can weaken the capabilities of oral cleaning and buffering, and the abilities of preventing bacterial infections, thereby increasing the risk of dental caries [40].

Our result showed that adolescents with longer Internet usage time had higher odds ratio of dental caries. The association remained significantly positive even after adjusting for demographics. We also found that frequency of sugary drinks intake worked as a mediator in the association between dental caries and Internet usage time. When adolescents dedicate substantial time and energy online, they were more likely to consume sugary drinks. Dohyun *et al*. [41] found the consumption of sugary drinks among adolescents who used the Internet for 1 hour or more was 1 time higher than that of those who used the Internet for less than 1 hour. A cross-sectional study among adolescents showed that daily sugar intake from sugary drinks increased by 1.99 grams for each extra hour of online games [42]. Frequent and prolonged exposure to sugary drinks generates an acidic plaque environment on the tooth surface, promoting the demineralization of dental enamel, subsequently causing caries.

Our results indicated that sleep duration played a mediating role in the association between Internet usage time and dental caries. Adolescents spending more time on the Internet tend to have late bedtimes and sleep for fewer hours. The risk of insufficient sleep among adolescents who used Internet for online gaming and social media was 1.16 times higher than that of those who never use [43]. The blue light from electronic screens at night may suppress melatonin secretion and disrupts the circadian rhythm, thereby affecting sleep quality [44]. Li *et al*. [45] found that excessive use of electronic devices before bedtime was significantly associated with insomnia and insufficient sleep. Insufficient sleep may cause significant changes in salivary function and immunity and then affect the dental health. Therefore, it is not difficult to understand why sleep duration worked as a mediator between Internet usage time and dental caries. Masanori *et al*. [46] had a similar finding as teenagers with Internet addiction had higher DMFT index than those without Internet addiction. Short sleep duration and frequent consumption of sugary drinks and snacks mediated the association between Internet addiction and dental caries.

There are several limitations of this study. Firstly, this study was an observational cross-sectional study, the causal relationships between Internet usage time and dental caries could not be confirmed. Secondly, the questionnaire used in this study relies on self-reports, which might risk recall bias and affect the accuracy of the results. In addition, the occurrence of dental caries is a result of the interaction of many factors. Although we found a significant association between Internet usage time and dental caries, this result should be interpreted with caution. As this study was part of the National Common Disease and Health Influencing Factors Monitoring Project, it was difficult for us to include too many questions in a questionnaire. So, some other influencing factors such as parent's socioeconomic status, the use of fluoride toothpaste, salivary function, accessibility of dental services, and different purposes of Internet use were not collected in the survey. These unmeasured factors may influence the observed results. Future studies should incorporate these factors to investigate their impact on dental caries.

5. Conclusions

Our study supported the hypothesis that Internet usage time was significantly associated with the prevalence of dental caries. Sugary drink consumption and sleep duration mediated the association between Internet usage time and dental caries. Adolescence is a critical period for oral development and the establishment of healthy habits. Parents and schools should collaborate to educate adolescents about the negative effects of excessive Internet use on oral health, guide adolescents to use the Internet in moderation, reduce sugary drink consumption, and ensure adequate sleep, thereby reducing the burden of dental caries and improving oral health among adolescents.

AUTHOR CONTRIBUTIONS

MYG and JCL—contributed to study design, data acquisition, analysis and interpretation, drafted the manuscript. YFJ and GML—contributed to data acquisition and analysis, critically revised the manuscript. YJLH, ZRP and MQZ—contributed to survey study and data acquisition, critically revised the manuscript. HRH and LL—contributed to conception, design of the study, critically revised the manuscript. All authors gave final approval and agree to be accountable for all aspects of the work.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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