Body mass index and dental caries experience in Nepalese schoolchildren

Saujanya Karki[1,2,3], Jari Päkkilä[4], Tapio Ryhänen[1], Marja-Liisa Laitala[1], Manoj Humagain[3], Marja Ojaniemi[2,5], and Vuokko Anttonen[1,2]

[1]Research Unit of Oral Health Sciences, University of Oulu, Finland, [2]Medical Research Center Oulu, University of Oulu, Oulu University Hospital, Finland, [3]School of Medical Sciences, Kathmandu University, Nepal, [4]Department of Mathematical Sciences, University of Oulu, Finland, [5]Department of Children and Adolescents, PEDEGO Research Center, University of Oulu, Finland.

Author Contributions

SK and VA made conception and designed the study. SK, MLL, MH and VA performed the acquisition of data. SK and JP performed the analysis and interpretation of data. SK, JP, TR, MLL and VA participated in preparing the manuscript. MH reviewed the manuscript and gave his comments. MO is a pediatric endocrinologist; she reviewed the manuscript and gave her critical comments.

Corresponding Author

Saujanya Karki
Research Unit of Oral Health Sciences
University of Oulu
POB 5281, Aapistie 3, FI- 90220, Oulu, Finland
saujanya.karki@oulu.fi

Abstract

Objectives: The aim was to investigate the severity of untreated dental caries among Nepalese schoolchildren and its association with their body mass index (BMI) using IOTF, WHO and Nepalese growth reference systems.

Methods: This school-based clinical cross-sectional study was conducted with three WHO index age groups (5–6-, 12-, and 15-year-olds) in 18 out of 75 districts of Nepal, selected using stratified random sampling. A total of 1,135 schoolchildren were included in the study. A validated structured questionnaire was used to assess the children's oral hygiene practices and dietary habits. Clinical oral examinations investigated the status of untreated dental caries in primary and permanent teeth (*dt/DT*) along with its consequences (*pufa/PUFA*). Later, the grade of severity of untreated dental caries (*GUDC*) was determined using both *dt/DT* and *pufa/PUFA*. Height (cm), weight (kg), waist circumference (cm), and hip circumference (cm) were measured and the body mass index (BMI), waist-to-hip ratio (WHR), and waist-to-height ratio (WHtR) were calculated. The findings were presented as proportions, and the Chi-square test was performed to compare differences between groups. Generalized linear mixed models with random effects assessed the association between the severity of untreated dental caries and the BMI.

Results: According to the IOTF, WHO, and Nepalese growth reference systems, the overall proportions of children with a low BMI were 38.6%, 15.4%, and 12.8%, and those with a high BMI were 7.9%, 4.6%, and 8.4%, respectively. Untreated dental caries was common among the youngest age group and those with infrequent tooth brushing habits or frequent consumption of sweet bakery products, sweets or candy, or tea with sugar. Neither a low nor a high BMI was associated either with dt+DT or with pufa+PUFA, after adjusting for confounders. However, both a low and a high BMI (all three references) were associated with the severity of dental caries or *GUDC.*

Conclusion: Regardless of the growth reference system used, children with either low or high BMI may be at risk of developing untreated dental caries lesions and related consequences. Both under- and over-weight/obese and dental caries share common risk factors, mostly dietary. Preventive and intervention approaches/strategies such as behavioral and dietary modifications should be implemented to improve both children's oral health and their nutrition in Nepal.

Keywords: Body mass index, children, dental caries, Nepal

Introduction

According to a recent report, the global prevalence of untreated dental caries among 12-year-olds is 69.4%[1]. Overall, the increase in the body mass index (BMI) among children and adolescents in high-income countries has plateaued[2], whereas the incidence of dental caries has markedly declined[3]. However, malnutrition (both under- and over-nutrition) and dental caries remain major and emerging public health threats in low- and middle-income countries[1,2]. Also in Nepal, the prevalence of untreated dental caries among children and adolescents has increased from the past[4,5], and the proportion of overweight and obese adolescents and adult Nepalese women (15–49-year-olds) has increased from 9.0% in 2006 to 22.0% in 2016[6].

The association between BMI and dental caries is still unclear[7]. Hooley et al. (2012) concluded in their systematic review that both high and low BMI are associated with children's dental caries[7]. Similarly, the association was also inconclusive in another systematic review, particularly concerning low- and middle-income countries as well as primary and permanent dentitions[8]. Both dental caries and obesity are multifactorial, and share common risk factors, such as dietary habits, life style, and socioeconomic conditions[9]. The availability and consumption of processed food products or drinks (containing a high amount of sugar, salt, or trans-fats), as well as sedentary lifestyle are considered major causative factors of overweight and obesity[10]. Likewise, frequent consumption of refined sugars and processed foods/drinks containing free sugars is considered a risk factor of dental caries[11]. In addition, poor oral hygiene habits have recently been reported to be associated with childhood and adolescent obesity[12,13] again, risk factors for poor oral health, particularly dental caries. For children with low BMI, lack of nutrients is a risk factor for common chronic diseases such as dental caries, and also may cause developmental dental disorders [14]. On the other hand, dental pain and infections due to dental caries may have an impact on eating and sleeping, thereby resulting in a low weight and growth impairment[15].

Body composition is influenced by environmental and nutritional, but also genetic factors. Therefore, children of different ethnicity may be misclassified as underweight/overweight/obese, if only one international growth reference system is used. Therefore, a recent study has recommended the use of nationality- or ethnicity-specific growth references[16]. There are three widely used growth reference systems, namely the World Health Organization (WHO), International Obesity Taskforce (IOTF), and Center for Disease Control and Prevention (CDC) reference systems. In addition, age- and gender-specified, population-specific BMI cut-off values were recently established for Nepalese

children and adolescents[17]. A systematic review (papers published between 1980 and 2010) revealed that six studies used the CDC growth charts, three studies used the IOTF growth centiles, two studies used the WHO growth reference system, and the rest three papers used the population-specific growth charts to define the growth status of children and adolescents[18]. However, using only one reference system without considering the ethnicity may lead to the misidentification of possible risk groups for dental caries.

The present study investigated the severity of untreated dental caries among Nepalese schoolchildren and its association with their BMI using three different growth reference systems, i.e. the IOTF[19], WHO[20] and Nepalese[17] systems. The hypothesis was that both a low and a high BMI are associated with untreated dental caries and its severity. We also investigated differences between the reference systems in their ability to detect associations between BMI and untreated dental caries.

Materials and Methods

This school-based clinical cross-sectional study was conducted among three WHO index age groups (5–6-year-olds, 12-year-olds, and 15-year-olds) in 18 out of 75 districts of Nepal during April–July 2016. The study protocol was approved by the Institutional Ethical Committee, Kathmandu University in Nepal (*IRC No. 60/15, KUSMS*), as well as by the Northern Ostrobothnia Hospital District in Finland (*18/2016*). The study was conducted according to the principles of the World Medical Association Declaration of Helsinki. Furthermore, a written permission to conduct the study was obtained from both the Ministry of Health and the Ministry of Education, Government of Nepal. The district health and education authorities also gave their permission for the study.

Study sites and samples

The methodology on the selection of the study sites and samples has been described in detail in a previous study[5]. Briefly, the districts were selected following the stratified random sampling method, considering the ecological regions (*Tarai, Hill,* and *Mountain*) and the administrative developmental regions *(Eastern, Central, Western, Mid-Western,* and *Far-Western*) of Nepal. Three districts from each five developmental regions were selected and they also represented each ecological region. Altogether 27 schools (*one to two schools per district*) were selected. The sample size was calculated using the G*power software (GPOWER version 3.1, Samsovej 21, 8382 Hinnerup, Denmark) with power calculation of 95% and the Mann-Whitney U test to analyze the difference between means (difference in the number of decayed primary and permanent teeth, d/D = 0.3) with alpha-type error

at 0.05. After a power calculation, the sample size of n=340 in each age group was considered sufficient. The study participation / response rate was 99% (1,137/1,151).

Prior to the study, the schools were contacted via an informative letter describing the purpose and procedure of the study. A written consent was obtained both from the school headmasters and from the parents of the youngest children (5–6-year-olds). A verbal consent was obtained and recorded from the children belonging to the oldest age groups (12- and 15-year-olds).

Oral health-related behaviors

A structured questionnaire was used to gather information on the children's oral hygiene practices and dietary habits. This structured questionnaire on oral health-related behavior was previously piloted and validated in Nepal[21]. Face-to-face interviews were conducted with the parents of the 5–6-year-olds, and the 12- and 15-year-old children were asked to answer a self-administered questionnaire.

Dental status

The dental examinations were performed in classrooms using external (LED) headlights, intra-oral mirrors, and the WHO Community Periodontal probes following the WHO guidelines and criteria[22]. The participants were asked to lie down on a bench in the supine position, and the examiners were seated behind them. Cross-infection control was maintained in all examination phases, as per the protocol.

The oral findings concerning the status of untreated dental caries (*decay in primary and permanent dentition, dt/DT*) and infections due to untreated dental caries (*visible pulp or pulp involvement, ulceration of the oral mucosa due to root fragments, a fistula,* or *an abscess, pufa/PUFA*) were recorded according to the standard criteria[22,23]. The dental status was evaluated at tooth level based on a visual-tactile examination, without using fiber-optic trans-illumination (FOTI) or radiography or without cleaning the teeth professionally or air-drying the teeth. The examination protocol and the quality control and quality assurance processes have been described in detail in a previous study[5]. In short, a survey team composed of three trained and calibrated Nepali dentists conducted the clinical examinations. The findings were recorded manually on data collection sheets by two trained dental hygienists, who acted as enumerators. The training of the dentists, which took place in April 2016, covered theoretical sessions followed by practical sessions. The trainers were senior researchers

familiar with similar studies. The inter-examiner kappa value for d/D was 0.87 and for pufa/PUFA 0.63, and the intra-examiner agreement ranged from 0.84 to 0.97.

Grading the severity of untreated dental caries (GUDC)

To achieve a broader understanding of the prevalence of untreated dental caries (*dt/DT*) and infection due to untreated dental caries (*pufa/PUFA*) based on clinical criteria, a new index, the grade of severity of untreated dental caries (GUDC), was created. The GUDC index consists of four grades determined based on the severity of both untreated dental caries (*dt/DT*) and its consequences (*pufa/PUFA*) (Table 1). The number of untreated dental caries lesions, including both primary (dt) and permanent teeth (DT) lesions, and the respective sum score of teeth with caries lesions per person were calculated. The sum score per person for pufa/PUFA was also calculated in the same manner as above. Later, the sum scores of *dt+DT* were classified into the following three categories: *healthy (0), moderate (1-4),* and *severe (more than 4)*. The sum scores of *pufa+PUFA* were also classified into three categories based on the median and the proportion of teeth with infection due to untreated dental caries. The categories were: *No infection (0%), moderate infection (10% or less),* and *severe infection (more than 10%)*. The categorizations were done according to the distribution of dt+DT and pufa+PUFA. The proportion of the sum score of *pufa+PUFA* was calculated separately for primary, mixed, and permanent dentition. Finally, the GUDC was computed and classified into four grades: *Grade 1, Grade 2, Grade 3,* and *Grade 4* (Table 1).

Anthropometric measurements

Height and weight were measured by asking the children to stand upright with the back of the head, buttocks, and heels touching the stadiometer (without leaning backward or forward) and only wearing a light school uniform (shirt, trousers/skirt, and undergarments) and no head gear (cap, ribbon, hairpins, etc.) or shoes. The height (cm) and weight (kg) of the children were measured using a portable stadiometer (Seca®, seca GmbH & Co. KG., Hamburg, Germany) and a self-zeroing portable electronic digital scale (Rossmax®, Rossmax Swiss GmbH, Berneck, Switzerland), respectively. The waist and hip circumferences (cm) were measured after asking the children to stand with their arms wide open and feet positioned close together. The waist circumference (WaC) was measured at the midway between lower ribs and the iliac crest, and the hip circumference was measured around the widest portion of the buttocks. The measurements were done using an inelastic plastic measuring tape (Prym®, William Prym Holding GmbH, Stolberg, Germany) held snugly (without compressing the skin) at a level parallel to the floor.

The body mass index (BMI) was calculated using the formula: weight divided by the square of height (kg/m^2). The waist-to-hip ratio (WHR) was calculated by dividing the waist circumference by the hip circumference, and the waist-to-height ratio (WHtR) by dividing the waist circumference by the height. During the training sessions, the members of the survey team were also trained to measure and record the anthropometric indices.

Statistical analysis

The manually recorded data were transferred into an electronic database to conduct analyses using the SPSS software (IBM SPSS Statistic for Windows, version 24.0. Armonk, NY: IBM Corp.). The kappa coefficient was used to measure the agreement between the untreated dental caries level *(healthy, moderate,* or *severe)*, infection due to untreated dental caries *(pufa/PUFA=0* and *pufa/PUFA≥1)*, and the GUDC. Likewise, Spearman's correlation coefficient (ρ) was used to assess the reliability between the indices.

The children were categorized according to their BMI to thin, normal, overweight, and obese using the three growth reference systems (i.e. IOTF[19], WHO[20], and Nepalese[17]). The participants were also dichotomized to normal and obese based on the cut-off values for central obesity (waist circumference, waist-to-hip ratio, waist-to-height ratio) of Nepalese children[17]. The distribution of thin, overweight, and obese children (using the three growth reference systems) was stratified by age and gender. Similarly, the distribution of dt+DT, pufa+PUFA, and GUDC in the participants was stratified by age (*5–6-, 12- and 15-year-olds*), gender (*boys/girls*), province, location (*urban/rural*), school type (*public/private*), tooth brushing frequency *(twice or more daily /once daily / several times per week),* dietary habits (*consumption of sweet bakery products / consumption of sweets or candy / consumption of tea with sugar*), as well as by the BMI (*IOTF, WHO, Nepalese*) and central obesity level (*WaC, WHR, WHtR*). The Chi-square test was applied to compare the differences between the groups.

For further analyses, the participants were categorized according to their BMI (all three reference systems) into children with a low (thinness/underweight), normal, or high (overweight and obese) BMI. Generalized linear mixed model with negative binomial distribution using random effect for sampling unit (schools) was conducted separately for each growth reference system, considering untreated dental caries (dt+DT), and its consequences (pufa+PUFA) as dependent variables. Sociodemographic characteristics (age, gender, location, and school type), frequency of tooth brushing, dietary habits, and the BMI were considered as covariates. The estimate of relative

risk / Rate Ratio (RR) and 95% confidence interval (95% CI) were estimated for both crude and adjusted models. Similarly, a mixed effects multinomial logistic regression analysis was performed to analyze the association between the GUDC as a dependent variable and the BMI as a covariate. In the model, sociodemographic characteristics (age, gender, location, school type), frequency of tooth brushing, and dietary habits were adjusted. For the Odds Ratio (OR) and 95% confidence interval (95% CI) were also calculated. The level of significance was set at $p \leq 0.05$ for all the statistical tests. The statistical analyses were carried out using the SPSS software and R version 3.4.3 (R Development Core Team, Vienna, Austria).

Results

Out of the total 1,137 participants who completed both the clinical examination and the survey, only two children were excluded due to missing anthropometric measurement values. The prevalence of thinness/underweight, overweight, and obesity in the study samples according to the three growth reference systems, stratified by age and gender, are presented in Table 2. The proportions of children with a low BMI (underweight or thinness) were 38.6%, 15.4%, and 12.8% according to the IOTF, WHO, and Nepalese reference systems, respectively. Similarly, the proportions of children with a high BMI (overweight and obese combined) were 7.9%, 4.6%, and 8.4% according to the IOTF, WHO, and Nepalese systems, respectively.

The agreement between the untreated dental caries (dt+DT) level and the new index used here for grading the severity of untreated dental caries lesions (i.e. GUDC) was substantial ($\kappa = 0.64$; *p-value <0.001*). Additionally, a fair agreement ($\kappa = 0.40$; *p-value <0.001*) was found between the level of infections due to untreated dental caries (pufa+PUFA) and the GUDC. Furthermore, the GUDC had strong reliability with both dt+DT ($\rho = 0.861$; *p-value <0.001)* and pufa+PUFA ($\rho = 0.817$*; p-value <0.001)*.

The associations of sociodemographic factors with dental caries and its consequences are presented in Table 3. In this study, two in three children had dt+DT>0, whereas one-fourth of the children had at least one tooth with pufa+PUFA (Table 3). In terms of the GUDC, almost half of the Nepalese schoolchildren achieved Grade 2 (only caries lesions) while a fifth were categorized into Grade 3 (caries lesions and pufa>0 in less than 10% of teeth). The youngest participants had significantly higher scores than the other age groups (dt+DT level, pufa+PUFA level, and the GUDC). The same was true for those brushing teeth only several times a week instead of on a daily basis, as well as for those consuming sweet bakery products, sweets or candies, or tea with sugar once or more daily.

Obese (IOTF, Nepalese) or overweight (WHO) children had high dt+DT, whereas pufa+PUFA scores were high for thin children (all reference systems). In addition, the GUDC grade 4 was the highest for thin (IOTF, Nepalese) or underweight (WHO) participants (Table 3).

After adjusting for confounders, the estimated relative risk was higher among younger children (*5–6-year-olds*), and those who consumed sweets or candies, or tea with sugar once or more daily compared with the rest. Neither a low nor a high BMI was associated with untreated dental caries (dt+DT) and its clinical consequences (pufa+PUFA), in adjusted models (Table 4).

According to the mixed effects multinomial logistic regression analysis (Fig. 1 A, B, and C), the association between high BMI (all reference systems) and the GUDC grade 3 was statistically significant (IOTF, OR 2.47, 95% CI 1.27–4.78; WHO, OR 4.27, 95% CI 1.75–10.56; Nepalese, OR 2.25, 95% CI 1.19–4.23). Similarly, low BMI (IOTF) was associated with the GUDC grade 4 (OR 2.15, 95% CI 1.17–3.93).

Discussion

This population-based cross-sectional survey revealed that untreated dental caries lesions co-exists with both low and high BMI values. The most severe or grade 4 of the GUDC (grading the severity of untreated dental caries) was associated with low BMI, whereas the grade 3 of the GUDC was associated with high BMI. However, untreated dental caries (dt+DT) and its clinical consequences (pufa+PUFA) alone were not associated with either of the BMI categories. This indicates that the nature of the association remains unclear. Furthermore, none of the reference systems was superior to the others in its ability to detect an association between BMI and untreated dental caries.

The high response rate (99%) in a population-based study with randomized sample sites, and the inclusion of children from all the ecological regions and ethnic groups of Nepal are the strengths of this study. Because the diseases (untreated dental caries and its consequences) were common in the study sample, and the distribution was over-dispersed (variance larger than the mean), we performed a generalized linear mixed model with negative binomial distribution. Furthermore, the models were adjusted for possible confounding factors, such as sociodemographic characteristics (*age, gender, location, and school type*), frequency of tooth brushing, and dietary habits (*sugar containing foods*). Despite this, the results showed a positive concurrent association between untreated dental caries and a low or high BMI. The GUDC index used in this study estimates the burden of both untreated dental caries lesions (dt/DT) and its consequences (pufa/PUFA) in a single tooth-wise entity. The GUDC

index simultaneously describes the severity of dental caries and the need for restorative work. In addition, in population-based epidemiological studies conducted in developing countries where radiographic assessment is not feasible, or might create a financial burden, the grading system used in this study could be practical. Furthermore, the index is simple (*can be obtained with single clinical examination*), brief (*four grades and less time consuming*), reliable (*strong Spearman correlation coefficient*), and reproducible (*fair to moderate Cohen's kappa value*). However, a detailed validation with some modifications to address shortcomings should be performed in the future. The cross-sectional nature of this study is one limitation. However, the estimate of the relative risk and a narrow confidence interval computed enhance the strength of the association in a cross-sectional study, which was true here as well. Another limitation is that both overweight and obese children were analyzed as one category, i.e. children with a high BMI. The proportion of obese children in each gender and age group was below 5% in this study, which is the reason to merge obese children with overweight children. It seems that being overweight/obese is still less common in Nepal than elsewhere although there are signs of an increasing trend of overweight among South Asian children and adolescents[2]. Furthermore, only one child had a high BMI (WHO) with the GUDC grade 4, leading to a wider confidence interval in Fig. 1.

An association between a high BMI and dental caries was established here; such a finding is contradictory to a recent study conducted in India, which showed an inverse association. In that study, a national growth reference system was used to classify BMI values[24]. Similarly, Liang et al. (2016) categorized BMI values according the WHO, IOTF, and CDC criteria and found an inverse relation[25]. The use of height-, weight-, and BMI-for-age z-scores among Bangladeshi children also showed negative association[26]. Our results are contradictory to those from Bangladesh, even though, the prevalence of pufa+PUFA>0 among our youngest schoolchildren was similar to Bangladeshi children[26]. The possible pathway of association between the BMI and dental caries remains unclear in this study, regardless of the regression model used. A similar finding was also observed in a systematic review by Hooley et al. (2012)[7]. The association also remained unclear in a hospital-based study conducted among Moroccan adults[27]. However, this nonlinear "U-shaped" relationship between risk factors and disease outcome is not rare in epidemiological studies[28].

The proportion of children with a low BMI was higher than the proportion of those with a high BMI, regardless of the reference system used in the present study sample. The relationship between untreated dental caries and low growth (BMI) and overall poor development may be explained by two mechanisms. The first one focuses on the overall poor child development caused by odontogenic

infections[29], while the second one emphasizes the impacts (direct impacts due to functional limitation and indirect impacts due to body response) of untreated dental caries on the growth of children[15]. Children could avoid eating because of the pain caused by dental caries or pulpitis or abscess, leading to low body weight. For instance, significant improvement on body weight was observed among Filipino children after the treatment of infected or carious teeth[30]. A high decay score was also associated with nutritional deficiency and low weight in South Korean children[31]. Nevertheless, the impact of functional limitation due to untreated dental caries and its consequences on the growth and development of children should be studied in future. In contrast, common risk factors between untreated dental caries and obesity are easier to link to each other, as explained earlier. Furthermore, children with decreased masticatory function due to pain caused by dental caries also tend to swallow large food particles, thereby compromising a nutritional diet, shifting towards processed foods that eventually can lead to overweight/obesity[32]. However, longitudinal epidemiological studies are naturally the best approach to identifying temporal relationships.

This study showed that two-thirds of Nepalese schoolchildren have untreated dental carious lesions with varied severity, with the poorest situation in the youngest age group (5–6-year-olds). Furthermore, the same is also true for infrequent tooth brushing and frequent consumption of sweet bakery products, sweets or candy, or tea with sugar. The majority of the participants (67%) in this study reported brushing their teeth only once daily; this could be one of the factors behind the high prevalence of untreated dental caries. Kumar et al. (2016) have reported an increased risk of carious lesions among those with infrequent tooth brushing habits[33]. Additionally, Nepalese children are exposed to sugar and sugar-containing foods at an early age (6–23-month-old), as reported in a recent survey conducted among mothers living in Kathmandu Valley[34]. It is necessary to modify the dietary habits among Nepalese children to have the intake of free sugars reduced to less than 10% of their total energy, as recommended by the WHO[35]. This would also benefit appropriate weight management as, although still low, the prevalence of overweight and obesity in Nepal is increasing[6]. Furthermore, considering the prevalence and distribution of sickness, the lack of oral health promotion and preventive programs as well as inadequate oral healthcare services should be taken into consideration while planning health and oral health policies.

In conclusion, irrespective of the reference system used, the majority of Nepalese schoolchildren have a normal BMI but the burden of low BMI is high. Both low and high BMI values (all the three reference systems) seem to be associated with an increased severity of untreated dental carious lesions. None of the reference systems was superior to another in their ability to detect an association

between the BMI and untreated dental caries. This study also supports the well-established association between dental caries (dt+DT level, pufa+PUFA>0, and high d/D+ pufa/PUFA, combined or GUDC) and various influencing factors (e.g. sociodemographic factors, oral hygiene behaviors, and dietary habits). Both malnutrition and dental caries are preventable through a common approach. Policy-makers should integrate preventive and intervention strategies to improve both oral and general health in Nepal.

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Table 1. Grading of severity of untreated dental caries (GUDC)

Untreated dental caries (dt+DT)		Infection due to untreated dental caries (pufa+PUFA)		Grading¥
0	None	0	No infection	Grade 1
1-4	Moderate	0		Grade 2
>4	Severe	0		
1-4	Moderate	≤10%	Moderate infection	Grade 3
>4	Severe	≤10%		
1-4	Moderate	>10%	Severe infection	Grade 4
>4	Severe	>10%		

¥ Children with dt+DT score = 0 were considered Grade 1, whereas those with moderate/severe dt+DT score with no pufa+PUFA were considered as Grade 2. Similarly, those with moderate/severe dt+DT score with ≤10% pufa+PUFA were considered as Grade 3 and finally those with moderate/severe dt+DT score with >10% pufa+PUFA were considered as Grade 4.

Table 2. Proportion (%) of Thinness, Overweight, and Obesity of Nepalese schoolchildren using the WHO reference, the IOTF reference, and Nepali reference values by age and gender.

Age (Years: Months)	Gender	n	IOTF reference[a]				WHO reference[b]			Nepali reference[c]		
			Thinness		Overweight	Obesity	Underweight	Overweight	Obesity	Thinness	Overweight	Obesity
			T-1	T-2								
5:0-5:11	Boys	84	39.3	8.4	7.1	-	6.0	4.8	-	4.8	15.5	3.6
	Girls	77	31.2	10.3	3.9	2.6	5.2	3.9	2.6	5.2	6.5	2.6
	Total	161	35.4	8.1	5.6	1.2	5.6	4.3	1.2	5.0	11.2	3.1
6:0-6:11	Boys	91	53.8	9.9	3.3	1.1	14.3	3.3	1.1	8.8	4.4	1.1
	Girls	86	41.9	15.1	2.3	3.5	14.0	1.2	2.3	15.1	2.3	3.5
	Total	177	48.0	12.4	2.8	2.3	14.1	2.3	1.7	11.9	3.4	2.3
12:0-12:11	Boys	213	45.5	12.7	3.8	0.5	19.7	2.3	0.5	12.7	3.3	0.5
	Girls	201	38.3	12.4	10.9	0.5	16.4	6.5	0.5	11.9	10.4	3.0
	Total	414	42.0	12.6	7.2	0.5	18.1	4.3	0.5	12.3	6.8	1.7
15:0-15:11	Boys	208	37.0	13.6	6.3	1.9	21.6	3.4	1.0	21.6	4.3	2.4
	Girls	175	25.1	10.9	11.4	0.6	10.9	4.0	-	10.3	7.4	0.6
	Total	383	31.6	13.1	8.6	1.3	16.7	3.7	0.5	16.4	5.7	1.6

[a] IOTF BMI cut-offs corresponding to BMI at age 18, using BMI Thinness Grade-1 (T-1) < 18.5 kg/m^2, and Thinness Grade-2 (T-2) < 17 kg/m^2 as Thinness, > 23 kg/m^2 as Overweight (unofficial Asian cut-offs), and > 27 kg/m^2 as Obesity (unofficial Asian cut-offs) (https://www.worldobesity.org/data/cut,points,used/newchildcutoffs/)

[b] WHO growth standard tables for ages 5–19-year-olds, using < -2 SD as Underweight, > +1 SD as Overweight, and > +2 SD as Obesity (http://www.who.int/growthref/who2007_bmi_for_age/en/)

[c] Nepalese BMI cut-off values[15], using < -1.2 SD or 12th percentile as Thinness, > +1.2 SD or 88th percentile as Overweight, and > +2.1 SD or 98th percentile as Obesity

Table 3. Proportion (%) of untreated dental caries (dt+DT), infection due to untreated dental caries (pufa+PUFA), and grading of the severity of untreated dental caries (GUDC) stratified by age, gender, location, school type, tooth brushing frequency, dietary habits, body mass index, waist circumference, waist-hip ratio, and waist-to-height ratio.

Variables		Untreated dental caries (dt + DT)				Infection due to untreated dental caries (pufa + PUFA)				Grading of the severity of untreated dental caries (GUDC)				
		Healthy (0)	Moderate (1-4)	Severe (>4)	*p-value*	0	≤10%	>10%	*p-value*	Grade 1	Grade 2	Grade 3	Grade 4	*p-value*
Age	5–6-year-olds	21.3	32.2	46.4	*<0.001*	53.0	28.4	18.6	*<0.001*	21.3	31.7	28.4	18.6	*<0.001*
	12-year-olds	33.6	55.1	11.4		80.4	17.1	2.4		33.6	46.9	17.1	2.4	
	15-year-olds	37.6	49.9	12.5		83.3	14.4	2.3		37.6	45.7	14.4	2.3	
Gender	Boys	27.5	50.0	22.5	*0.011*	73.3	19.6	7.0	*0.970*	27.5	45.8	19.6	7.0	*0.017*
	Girls	35.4	42.7	21.9		73.1	19.5	7.4		35.4	37.7	19.5	7.4	
Provinces	1	25.8	48.5	25.8	*0.001*	69.6	21.1	9.3	*0.002*	25.8	43.8	21.1	9.3	*<0.001*
	2	56.6	32.5	10.8		89.2	9.6	1.2		56.6	32.5	9.6	1.2	
	3	27.8	50.2	21.9		76.8	21.5	1.7		27.8	48.9	21.5	1.7	
	4	26.2	48.8	25.0		66.7	25.0	8.3		26.2	40.5	25.0	8.3	
	5	31.3	47.0	21.7		71.1	19.9	9.0		31.3	39.8	19.9	9.0	
	6	34.1	40.3	25.6		71.3	17.8	10.9		34.1	37.2	17.8	10.9	
	7	30.6	48.3	21.1		71.9	18.6	9.5		30.6	41.3	18.6	9.5	
Location	Urban	31.7	47.9	20.3	*0.261*	74.5	19.7	5.8	*0.133*	31.7	42.8	19.7	5.8	*0.257*
	Rural	30.8	44.9	24.3		71.7	19.4	8.9		30.8	40.9	19.4	8.9	
School types	Public	32.5	48.6	18.9	*0.004*	75.8	17.7	6.5	*0.055*	32.5	43.3	17.7	6.5	*0.121*
	Private	29.4	43.3	27.4		69.3	22.4	8.3		29.4	39.9	22.4	8.3	
Frequency of tooth brushing	Twice or more daily	35.2	50.5	14.3	*<0.001*	77.6	20.5	1.9	*0.003*	35.2	20.5	20.5	1.9	*0.007*
	Once daily	30.5	48.9	20.6		75.4	17.9	6.7		30.5	17.9	17.9	6.7	
	Several times in a week	28.3	38.4	33.3		64.0	24.6	10.9		28.3	24.6	24.6	10.9	
Sweet bakery products	Several times in a month	31.0	52.8	16.3	*0.002*	78.2	18.0	3.8	*0.006*	31.0	47.2	18.0	3.8	*0.014*
	Several times in a week	33.0	46.2	20.8		75.6	17.2	7.2		33.0	42.7	17.2	7.2	
	Once or more Daily	29.9	42.2	27.9		67.9	23.1	9.1		29.9	38.0	23.1	9.1	
Sweets or candies	Several times in a month	35.9	47.8	16.3	*0.007*	82.4	14.0	3.6	*<0.001*	35.9	46.6	14.0	3.6	*0.001*
	Several times in a week	29.4	50.0	20.6		70.3	22.4	7.3		29.4	40.9	22.4	7.3	
	Once or more Daily	27.5	46.2	26.3		68.9	22.7	8.4		27.5	41.5	22.7	8.4	
Tea with sugar	Several times in a month	37.3	44.8	17.9	0.040	80.3	16.3	3.4	0.005	37.3	42.9	16.3	3.4	0.006
	Several times in a week	32.0	43.7	24.3		79.6	16.5	3.9		32.0	47.6	16.5	3.9	
	Once or more Daily	27.9	50.2	22.0		70.5	21.3	8.1		27.9	42.7	21.3	8.1	
IOTF reference	Thinness	27.0	45.8	27.2	*0.003*	68.2	20.8	11.0	*<0.001*	27.0	41.2	20.8	11.0	*<0.001*
	Normal	35.4	46.9	17.8		77.8	16.9	5.3		35.4	42.4	16.9	5.3	
	Overweight	26.0	46.8	27.3		66.2	32.5	1.3		26.0	40.3	32.5	1.3	
	Obese	15.4	53.8	30.8		69.2	23.1	7.7		15.4	53.8	23.1	7.7	
WHO reference	Underweight	26.0	43.4	30.6	*0.004*	67.1	20.8	12.1	*0.001*	26.0	41.1	20.8	12.1	*0.002*
	Normal	33.2	46.8	20.0		75.1	18.4	6.6		33.2	41.9	18.4	6.6	
	Overweight	14.0	55.8	30.2		60.5	39.5	-		14.0	46.5	39.5	-	
	Obese	22.2	33.3	44.4		66.7	22.2	11.1		22.2	44.4	22.2	11.1	
Nepalese reference	Thinness	25.2	43.4	31.5	*0.023*	69.2	20.3	10.5	*0.031*	25.2	44.1	20.3	10.5	*0.034*
	Normal	33.0	47.0	20.0		74.8	18.2	7.0		33.0	41.7	18.2	7.0	
	Overweight	25.7	45.9	28.4		62.2	33.8	4.1		25.7	36.5	33.8	4.1	
	Obese	18.2	50.0	31.8		72.7	22.7	4.5		18.2	54.5	22.7	4.5	
Waist circumference	Normal	30.9	46.7	22.3	*0.737*	73.8	18.7	7.5	*0.069*	30.9	42.8	18.7	7.5	*0.062*
	Obese	34.5	44.5	20.9		68.2	27.3	4.5		34.5	33.6	27.3	4.5	
Waist-to-Hip Ratio	Normal	32.4	46.0	21.7	*0.521*	74.9	19.0	6.1	*0.068*	32.4	42.5	19.0	6.1	*0.137*
	Obese	29.1	47.6	23.3		69.8	20.6	9.5		29.1	40.7	20.6	9.5	
Waist-to-height ratio	Normal	31.7	46.6	21.7	*0.388*	73.8	19.1	7.1	*0.325*	31.7	42.4	19.1	7.1	*0.498*
	Obese	27.2	45.6	27.2		67.0	24.3	8.7		27.2	39.8	24.3	8.7	

Table 4. Generalized linear model with negative binomial distribution of the untreated dental caries (dt+DT) and infection due to untreated dental caries (pufa+PUFA) as dependent variables and socio-demography (age, gender, location, school types), frequency of tooth brushing, dietary habits, and BMI (the IOTF, WHO, and Nepalese growth references) as covariates.

Explanatory factors		Untreated dental caries (dt + DT) RR (95% CI)			Infection due to untreated dental caries (pufa + PUFA) RR (95% CI)		
		IOTF reference	WHO reference	Nepalese reference	IOTF reference	WHO reference	Nepalese reference
Age	5–6-year-olds	2.68 (2.23-3.22)**	2.70 (2.25-3.25)**	2.70 (2.25-3.24)**	2.27 (1.67-3.06)**	2.28 (1.68-3.10)**	2.31 (1.70-3.12)**
	12-year-olds	1.01 (0.86-1.19)	1.01 (0.86-1.18)	1.02 (0.86-1.19)	1.04 (0.80-1.35)	1.05 (0.80-1.37)	1.05 (0.80-1.37)
	15-year-olds	1.00	1.00	1.00	1.00	1.00	1.00
Gender	Boys	1.21 (1.05-1.39)**	1.22 (1.06-1.40)**	1.22 (1.06-1.40)**	1.04 (0.83-1.31)	1.05 (0.83-1.32)	1.07 (0.85-1.34)
	Girls	1.00	1.00	1.00	1.00	1.00	1.00
Location	Urban	0.99 (0.86-1.14)	0.99 (0.86-1.14)	0.99 (0.86-1.14)	0.91 (0.72-1.15)	0.91 (0.72-1.14)	0.91 (0.72-1.14)
	Rural	1.00	1.00	1.00	1.00	1.00	1.00
School Types	Private	1.07 (0.93-1.24)	1.07 (0.93-1.24)	1.07 (0.93-1.23)	1.03 (0.81-1.31)	1.03 (0.81-1.31)	1.02 (0.80-1.29)
	Public	1.00	1.00	1.00	1.00	1.00	1.00
Frequency of tooth brushing	Once daily	1.04 (0.81- 1.33)	1.05 (0.80-1.32)	1.03 (0.81-1.33)	1.16 (0.76-1.74)	1.15 (0.76-1.45)	1.15 (0.76-1.75)
	Several times in a week	1.06 (0.88-1.27)	1.06 (0.88-1.27)	1.06 (0.89-1.27)	1.21 (0.89-1.62)	1.21 (0.89-1.64)	1.20 (0.89-1.63)
	Twice or more daily	1.00	1.00	1.00	1.00	1.00	1.00
Sweet Bakery Products	Once or more daily	0.97 (0.81-1.15)	0.96 (0.81-1.14)	0.96 (0.81-1.15)	0.98 (0.73-1.30)	0.98 (0.73-1.30)	0.98 (0.73-1.30)
	Several times in a week	0.99 (0.84-1.18)	0.99 (0.83- 1.18)	0.99 (0.83-1.18)	1.02 (0.76-1.34)	1.02 (0.77-1.35)	1.02 (0.76-1.35)
	Several times in a month	1.00	1.00	1.00	1.00	1.00	1.00
Sweets or Candies	Once or more daily	1.29 (1.09-1.52)*	1.30 (1.10-1.53)*	1.30 (1.10-1.53)*	1.27 (0.96-1.68)	1.27 (0.96-1.68)	1.30 (0.98-1.71)
	Several times in a week	1.14 (0.96-1.58)	1.15 (0.97-1.37)	1.15 (0.97-1.36)	1.27 (0.96-1.69)	1.27 (0.96-1.69)	1.29 (0.97-1.72)
	Several times in a month	1.00	1.00	1.00	1.00	1.00	1.00
Tea with Sugar	Once or more daily	1.19 (1.01-1.38)*	1.17 (0.99-1.37)	1.18 (1.01-1.38)*	1.22 (0.95-1.58)	1.24 (0.96-1.61)	1.22 (0.95-1.59)
	Several times in a week	1.23 (0.96-1.67)	1.22 (0.95-1.56)	1.23 (0.96-1.59)	0.99 (0.65-1.50)	1.00 (0.65-1.53)	0.99 (0.65-1.52)
	Several times in a month	1.00	1.00	1.00	1.00	1.00	1.00
BMI	Low	1.11 (0.96-1.28)	1.07 (0.89-1.30)	1.11 (0.90-1.36)	1.15 (0.91-1.47)	1.13 (0.83-1.55)	1.09 (0.78-1.53)
	High	1.18 (0.92-1.52)	1.30 (0.96-1.77)	1.20 (0.96-1.52)	0.96 (0.63-1.48)	0.86 (0.50-1.47)	1.07 (0.71-1.59)
	Normal	1.00	1.00	1.00	1.00	1.00	1.00

**p-value <0.001- *p-value ≤0.05*
RR (95% CI): Rate Ratio (95% confidence interval)

Fig 1. Mixed effects multinomial logistic regression models for the association between the grading of the severity of untreated dental caries (GUDC) and BMI (*IOTF- WHO- and Nepalese growth references*). The odds ratio (95% confidence interval) for (A) grade 1 vs grade 2, (B) grade 1 vs grade 3, and (C) grade 1 vs grade 4 in children with low and high BMI using normal BMI group as reference. In each model, age, gender, location, school types, frequency of tooth brushing, and dietary habits were adjusted.