Erosive tooth wear and caries experience in children and adolescents with obesity

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ABSTRACT

Clinical Significance: A large consumption of fermentable carbohydrates, for instance the high intake of sweetened beverages, is an important risk factor for overweight and obesity. As lemonades and fruit juices present high sugar content and quite low pH-values, overweight and obese children might also have an increased risk for dental caries and erosive tooth wear.

Objectives: The aim was to analyze the prevalence and severity of erosive tooth wear and caries experience in children and adolescents with overweight, obesity and extreme obesity compared to children with normal weight and to determine a possible association between erosive tooth wear and caries experience.

Methods: 223 children (4–17 years, n = 1476 primary and n = 4110 permanent teeth) were examined using standardized dental indices (BEWE, ICDAS, DMFT). Demographic and socio-economic data, eating habits, oral hygiene, fluoride supply and details of medical history were obtained from a questionnaire. Weight classification was based on age- and gender-specific relative body mass indices (BMI). Statistical analyses were done by Chi²-tests, Kruskal-Wallis tests, logistic and linear regressions. To determine a possible association between erosive tooth wear and caries experience Chi²-tests (prevalence to prevalence) and Spearman correlations (severity to severity) were performed (p < 0.05).

Results: Erosive tooth wear and caries experience in primary and permanent teeth were significantly increased in children with obesity and extreme obesity compared to normal weight children (p < 0.05). Higher BMI, age, gender, and the consumption of erosive snacks/beverages were identified as statistically significant risk factors for erosive tooth wear. Higher BMI, age, socio-economic factors, poor toothbrushing habits, and consumption of cariogenic beverages were identified as significant caries risk factors. Erosive tooth wear and caries showed a weak correlation in children with (extreme) obesity (Φ = 0.110 to 0.248).

Conclusions: Higher BMI of children and adolescents is significantly associated with a higher risk for erosive tooth wear and caries.

1. Introduction

The prevalence of childhood overweight and obesity has increased since the 1980s. Nevertheless, in countries with higher income, recent surveys showed a post-millennial stagnation. In Germany, the current prevalence of childhood overweight and obesity were found to be 15.4% and 5.9%, respectively. Being associated with several risk factors such as hypertension, hyperinsulinemia and hyperlipidemia, childhood obesity presents an immediate and long-term health risk for diabetes mellitus, heart diseases, osteoarthritis and adult obesity [1–3].

One of the main reasons for the increase of overweight and obesity

is the large intake of fermentable carbohydrates, for instance the high consumption of sweetened beverages. Dietary free sugars are also the most important risk factor for the development of dental caries [4]. However, studies evaluating a possible association between body weight of children and adolescents and dental caries prevalence have revealed inconsistent results: Whereas many studies reported a significant association [5–7], others revealed an inverse [8,9] or no relationship at all [10,11]. These contradicting results might be partly explained by methodological differences, e.g. different methods of dental examination or different socioeconomic background of the study populations. A significant association was found most frequently in

Table 1

Prevalence (total number of affected children or teeth (n), %) and severity (BEWE score per tooth, mean ± standard deviation [95% confidence intervals]) of erosive tooth wear in primary and permanent teeth and prevalence (n, %), severity (BEWE score sum, mean ± standard deviation [95% confidence intervals]) and percentage of affected teeth in children with primary or permanent teeth in relation to weight classification groups. Significant differences between weight classification groups are marked with different letters.

		Weight classification group				
		Normal weight	Overweight	Obesity	Extreme obesity	Total
Primary teeth	**Erosive tooth wear** n (%)	123 (24.7)[a]	55 (36.4)[b]	224 (41.7)[b]	108 (34.6)[b]	210 (34.1)
	BEWE score	0.4 ± 0.8[a] [0.3-0.5]	0.5 ± 0.8[a,b] [0.4-0.6]	0.6 ± 0.8[b] [0.5-0.6]	0.5 ± 0.7[a,b] [0.4-0.6]	0.5 ± 0.8 [0.4-0.5]
Children with primary teeth	**Erosive tooth wear** n (%)	24 (63.2)[a]	13 (86.7)[a]	47 (77.0)[a]	21 (80.8)[a]	105 (75.0)
	Affected teeth per patient (%)	31.5 ± 32.9[a] [20.7-42.3]	43.2 ± 29.3[a] [27.0-59.4]	49.4 ± 35.6[a] [39.9-58.5]	39.3 ± 31.7[a] [26.5-52.1]	41.9 ± 34.0 [36.1-47.5]
	BEWE score sum	3.2 ± 3.5[a] [2.0-4.3]	3.7 ± 3.1[a] [2.0-5.4]	3.4 ± 3.0[a] [2.6-4.1]	3.4 ± 2.7[a] [2.3-4.5]	3.4 ± 3.1 [2.9-3.9]
Permanent teeth	**Erosive tooth wear** n (%)	8 (1.0)[a]	2 (0.4)[a]	42 (2.3)[b]	43 (4.3)[c]	95 (2.3)
	BEWE score	0.0 ± 0.2[a] [0.0-0.0]	0.0 ± 0.1[a] [0.0-0.0]	0.0 ± 0.3[a] [0.0-0.1]	0.1 ± 0.3[b] [0.0-0.1]	0.0 ± 0.3 [0.0-0.0]
Children with permanent teeth	**Erosive tooth wear** n (%)	2 (4.3)[a]	1 (4.0)[a,b]	20 (22.0)[b]	13 (28.9)[c]	36 (17.4)
	Affected teeth per patient (%)	0.6 ± 3.4[a] [0.0-1.7]	0.3 ± 1.4[a,b] [0.0-0.9]	2.1 ± 5.4[a,b] [1.0-3.2]	4.5 ± 8.5[b] [1.9-7.0]	2.1 ± 5.7 [1.3-2.9]
	BEWE score sum	0.1 ± 0.3[a] [0.0-0.2]	0.1 ± 0.4[a,b] [0.0-0.2]	0.5 ± 1.1[a,b] [0.2-0.7]	1.0 ± 2.0[b] [0.3-1.6]	0.4 ± 1.3 [0.3-0.6]

studies from Europe and the United States, while studies from Asia and South American countries mostly revealed an inverse association [12,13].

As many sugar-sweetened beverages, lemonades and fruit juices present a quite low pH-value [14], they might be not only a potential risk factor for obesity and caries, but also for erosive tooth wear. While the overall prevalence of dental caries is decreasing substantially over the past decades, erosive tooth wear has gained increasing importance [15]. Erosive tooth wear is defined as a progressive loss of dental hard tissue induced by an acid-related chemical-mechanical process not involving bacteria [16]. Acidic sources can either be from intrinsic or extrinsic origin. While frequent vomiting or gastroesophageal reflux cause intrinsic erosions, a high consumption of soft drinks, juices, fruits or vegetables is the main reason for extrinsic erosion. A recent study in Swedish young adults with severe erosive tooth wear identified a high BMI as one significant risk factor among others [17]. However, it has so far hardly been investigated whether patients with overweight and obesity are at higher risk for erosive tooth wear [18] and whether caries and erosive tooth wear are correlated, especially in patients with overweight and obesity.

Thus, this study aimed at analyzing the prevalence and severities of erosive tooth wear and caries in children with overweight, obesity and extreme obesity compared to children with normal weight. Secondly, this study aimed at determining a possible association between erosive tooth wear and caries experience. The null hypotheses were that 1) the prevalence and severity of erosive tooth wear and caries experience is not affected by body weight and that 2) the erosive tooth wear and caries experience are neither correlated in children with normal weight nor in children with obesity.

2. Methods

The present study was performed between February and December 2016 at the University Medical Center of Göttingen, Germany. The guidelines of the study followed the Declaration of Helsinki. Ethical approval was obtained from the local ethics committee (file nr. 22/6/15). The study was registered at the International Clinical Trials Registry Platform by the German Registry of Clinical Trials (DRKS00010671).

2.1. Sample population

All Patients of the Department of Pediatrics and Adolescent Medicine and the Outpatient Clinic for Pediatric Obesity of the University Medical Center Göttingen fulfilling the inclusion criteria were invited to participate in the study. Pre-selection was based on the reports of the Department of Pediatrics and Adolescent Medicine and the Outpatient Clinic for Pediatric Obesity.

Inclusion criteria were:

- age: 4–17 years

In order to avoid confounders potentially affecting oral hygiene or salivary exclusion criteria were:

- lack of children's cooperation or refusal for participation
- general illness or neurological, psychological or syndromal disease restricting seriously motor and/or cognitive abilities
- general illness affecting saliva composition and/or flow (e.g. Sjogren syndrome).

Children and parents/legal guardian(s) received oral and written information; written consent was obtained from parents/legal guardian(s) and - depending on the writing ability - from the children before enrollment.

2.2. Clinical examination and questionnaire

All examinations were performed by one dentist (A.S.). During examination, the child was sitting on an examination table or chair in front of the examiner. Optimal lightening was assured by a standard dental LED head light (Denshine, Peking, China). All tooth surfaces were examined for erosive tooth wear using the "Basic Erosive Wear Examination" (BEWE, Code 0: no erosive tooth wear, Code 1: Initial loss of enamel surface, Code 2: distinct defect, hard tissue loss less than 50% of the surface, Code 3: hard tissue loss more than 50% of the surface [19]).

To determine dental caries, the "International Caries Detection and Assessment System II" (Code 0: sound; 1-2: visual changes in enamel, 3:

Table 2

Tooth- and subject-related variables with significant influence on prevalence or severity of erosive tooth wear. For analysis being performed by logistic regressions odds ratios (OR) and 95% confidence intervals (CI) are given. OR values lower than "1" indicate inverse associations (e.g. primary teeth with erosive tooth wear are less likely to show dental caries than primary teeth without erosive tooth wear), values higher than "1" indicate a direct association ("risk factor", e.g. increasing risk of erosive tooth wear in children with primary teeth with increasing BMI). In metric parameters, the corresponding risk increases by the OR value given when the parameter rises by +1. For example, in concern of children with primary teeth, an increase of body-mass-index percentiles (BMI) from 50 (normal weight) to 98 (obese) implies an increase of risk of 2,5% times 48 which is equal to a rise of our observed prevalence from 63% to 76%.

		Independent variables	OR [95% CI]	p-value	Estimate
Primary teeth	Prevalence (erosive tooth wear)	BMI	1.013 [1.006-1.020]	< 0.001	
		Age	1.381[1.303-1.464]	< 0.001	
		Gender		0.011	
		Male gender	Reference		
		Female gender	0.737 [0.577-0.932]		
		Background		0.010	
		Native	Reference		
		Migrant	0.678 [0.502-0.911]		
		ICDAS-value	0.668 [0.581-0.796]	< 0.001	
	Severity (BEWE score)	BMI		0.011	0.002
		Age		< 0.001	0.103
		Gender		< 0.001	
		Male gender			Reference
		Female gender			−0.249
		ICDAS-value		< 0.001	−0.102
Children with primary teeth	Prevalence (erosive tooth wear)	BMI	1.025 [1.005-1.046]	0.015	
	Affected teeth per patient (%)	Metabolic syndrome		0.046	
		None			Reference
		Yes			0.171
		Age		< 0.001	0.042
		Background		0.017	
		Native			Reference
		Migrant			−0.150
	Severity (BEWE score sum)	Gender		0.024	
		Male gender			Reference
		Female gender			−1.165
		Toothpaste fluoride concentration according to with the recommendations of the German Society of Dental, Oral and Craniomandibular Sciences (DGZMK) [52]		0.004	
		age-appropriate or higher			Reference
		lower than recommended			1.539
Permanent teeth	Prevalence (erosive tooth wear)	Background		0.010	
		Native	Reference		
		Migrant	2.013 [0.733-2.978]		
		Frequency of erosive beverages		0.049	
		Never or not more than some times per week	Reference		
		Daily or at least several times per week	4.074 [1.327-7.259]		
		Toothbrushing			
		Only manual toothbrush	Reference		
		Only electric toothbrush	0.649 [0.485-1.704]	> 0.05	
		With electric and manual toothbrush	1.952 [1.201-2.972]	0.021	
	Severity (BEWE score)	Age		< 0.001	0.027
		Patient		0.003	0.010
		Snacks		0.024	
		Not erosive			Reference
		Erosive			0.087
		Number of siblings		< 0.001	0.153
		Background		< 0.001	
		Native			Reference
		Migrant			0.284
Children with permanent teeth	Prevalence (erosive tooth wear)	BMI	1.041 [1.010-1.097]	0.045	
		Age	1.240 [1.089-1.427]	0.002	
	Affected teeth per patient (%)	BMI		0.039	0.001
	Severity (BEWE score sum)	Snacks		0.034	
		Not erosive			Reference
		Erosive			1.500

For analysis being performed by multiple regressions estimates are given. Negative estimate values indicate an indirect association(e.g. primary teeth: the risk for erosive tooth wear decreases with increasing dental decay), positive values indicate a direct association (e.g.: primary teeth: the risk for more severe erosive tooth wear increases with increasing BMI percentiles and increasing age).

Table 3

Caries experience at two cut-off-levels (total number of affected children or teeth (n), %) in primary and permanent teeth and caries experience (n, %), severity (dmft/DMFT, mean ± standard deviation [95% confidence intervals]) and percentage of affected teeth in children presenting primary or permanent teeth in relation to weight classification groups. Significant differences between weight classification groups are marked with different small letters.

		Weight classification groups				
		Normal weight	Overweight	Obesity	Extreme obesity	Total
Primary teeth	Caries experience (d_{1-6}mft > 0) n (%)	54 (10.9)[a]	21 (13.9)[a,b]	127 (23.6)[b]	78 (25.0)[b]	280 (18.7)
	Caries experience (d_{3-6}mft > 0) n (%)	36 (7.2)[a]	15 (9.9)[a,b]	103 (19.1)[b]	54 (17.3)[b]	208 (13.9)
Children with primary teeth	Caries experience (d_{1-6}mft > 0) n (%)	19 (50.0)[a]	8 (53.3)[a]	34 (55.7)[a]	19 (73.1)[a]	80 (57.1)
	Affected teeth per patient (%, d_{1-6}mft > 0)	16.0 ± 27.6[a] [7.0-25.1]	15.0 ± 23.4[a] [1.9-28.4]	23.9 ± 24.0[a] [16.2-31.9]	29.7 ± 29.6[a] [17.7-41.6]	21.9 ± 28.9 [17.1-26.8]
	Severity (d_{1-6}mft)	1.4 ± 2.2[a] [0.7-2.2]	1.5 ± 2.1[a] [0.3-2.6]	2.1 ± 2.8[a] [1.4-2.8]	2.9 ± 2.9[a] [1.8-4.1]	2.0 ± 2.7 [1.5-2.4]
	Caries experience (d_{3-6}mft > 0) n (%)	15 (39.5)[a]	4 (26.7)[a]	28 (45.9)[a]	15 (57.7)[a]	62 (44.3)
	Affected teeth per patient (%, d_{3-6}mft > 0)	12.9 ± 26.9[a] [4.1-21.8]	11.6 ± 24.7[a] [0.0-25.3]	18.7 ± 26.0[a] [12.0-25.5]	20.3 ± 24.2[a] [10.5-30.1]	16.6 ± 25.7 [12.3-21.0]
	Severity (d_{3-6}mft)	0.9 ± 1.9[a] [0.3-1.6]	1.1 ± 2.2[a] [0.0-2.3]	1.7 ± 2.5[a] [1.1-2.3]	2.0 ± 2.6[a] [1.0-3.1]	1.5 ± 2.3 [1.5-2.4]
Permanent teeth	Caries experience (D_{1-6}MFT > 0) n (%)	68 (8.8)[a]	62 (11.6)[a]	326 (18.0)[b]	186 (18.7)[b]	642 (15.6)
	Caries experience (D_{3-6}MFT > 0) n (%)	30 (3.9)[a]	9 (1.7)[a]	40 (2.2)[a]	30 (3.0)[a]	109 (2.7)
Children with permanent teeth	Caries experience (D_{1-6}MFT > 0) n (%)	16 (34.8)[a]	15 (60.0)[a,b]	63 (69.2)[b]	31 (68.9)[b]	125 (60.4)
	Affected teeth per patient (%, D_{1-6}MFT > 0)	6.6 ± 12.7[a] [2.8-10.4]	9.9 ± 12.2[a,b] [4.8-14.9]	16.1 ± 16.8[b] [12.6-19.6]	16.0 ± 16.9[b] [10.9-21.1]	13.2 ± 15.9 [11.0-15.4]
	Severity (D_{1-6}MFT)	1.5 ± 3.3[a] [0.5-2.4]	2.5 ± 3.2[a,b] [1.2-3.8]	3.6 ± 4.2[b] [2.7-4.5]	4.1 ± 4.8[b] [2.7-5.6]	3.1 ± 4.1 [2.5-3.7]
	Caries experience (D_{3-6}MFT > 0) n (%)	10 (21.7)[a]	6 (24.0)[a]	23 (25.3)[a]	11 (24.4)[a]	50 (24.2)
	Affected teeth per patient (%, D_{3-6}MFT > 0)	3.1 ± 7.4[a] [0.8-5.5]	1.4 ± 2.9[a] [0.2-2.6]	2.1 ± 4.3[a] [1.2-3.0]	2.4 ± 5.1[a] [0.9-3.9]	2.3 ± 5.3 [1.6-3.0]
	Severity (D_{3-6}MFT)	0.7 ± 2.0[a] [0.1-1.2]	0.4 ± 0.8[a] [0.0-0.7]	0.4 ± 0.9[a] [0.2-0.6]	0.7 ± 1.5[a] [0.2-1.1]	0.5 ± 1.3 [0.3-0.7]

enamel breakdown, 4. dentin shadow, 5: distinct cavity in dentin, 6: extensive cavity in dentin [20]) was used. Teeth with ICDAS 5 or 6, restorations covering all tooth surfaces or orthodontic bands were not considered diagnosing erosive tooth wear using BEWE. Teeth with restorations covering all surfaces or orthodontic bands were not considered for caries examination using ICDAS. The reasons for missing or extracted teeth (trauma/caries) were obtained verbally from the child and the parents for determining the DMFT/dmft (number of teeth being decayed, filled or missing because of dental caries).

Before starting the examinations, intensive calibration exercises were carried out. To validate the calibration process, inter-examiner (between A.S. and C.T.) and intra-examiner reliabilities were analysed in a subgroup of 29 patients (712 teeth) and 23 patients (573 teeth), respectively. Inter-examiner weighted Kappa amounted to 0.91 (BEWE) and 0.68 (ICDAS), and intra-examiner weighted Kappa to 0.95 (BEWE) and 0.78 (ICDAS).

According to the recommendations of the "European Childhood Obesity Group (ECOG)" and the "German Adiposity In Children And Young Adults Work Group (AGA)" weight classification was based on age- and gender-specific relative body mass indices (body mass index-percentiles, BMI) at the day of the dental examination: children with BMI between the 10th and 90th percentiles [−1.64 to +1.64 standard

deviation score (SDS)] were classified as normal weight, children with BMI between the 90th and 97th BMI percentiles (+1.64 to +2.17 SDS) as overweight, children with BMI above the 97th percentile (+2.17 to +2.81 SDS) as obese and children with BMI above the 99.5th percentile (> 2.81 SDS) as extremely obese [21–23]. To preserve homogeneity of groups, underweight children (below the 10th BMI percentile, n = 2) were excluded from the final analysis. Standardized body height and weight measurements were performed with the child in underwear and without wearing shoes (Ulmer Stadiometer, Busse Design und Engineering GmbH, Elchingen, Germany and electrical balance Model 701, seca GmbH & Co. KG, Hamburg, Germany).

A questionnaire was filled out by each child and its parents/legal(s) at the day of the clinical examination. The questions were based on the Fourth German Oral Health Study (DMS IV) [24] and previous studies investigating erosive tooth wear in children [25,26]. Eighteen open and close-ended questions queried information about demographic data (age, gender, number of siblings, nationality and family income), eating habits (amount and frequency of beverages and food), oral hygiene (time and frequency of tooth-brushing, kind of toothbrush and toothpaste), fluoride supply and details of medical history including diabetes, asthma, gastroesophageal reflux, frequent vomiting and type and frequency of (acidic) medication. Definition of metabolic syndrome was

Table 4

Tooth- and subject-related variables with significant influence on caries experience or severity. For analysis being performed by logistic regressions odds ratios (OR) and 95% confidence intervals (CI) are given. For analysis being performed by multiple regressions estimates are given. Further clues concerning the interpretation of the results are given in the caption of Table 2.

		Independent variables	OR [95% CI]	p-value	Estimate
Primary teeth	Prevalence of caries experience (d_{1-6}mft > 0)	BMI	1.017 [1.007-1.027]	< 0.001	
		Age	1.181 [1.086-1.284]	< 0.001	
		BEWE score	0.582 [0.446-0.745]	< 0.001	
		Toothbrushing habits		< 0.001	
		Poor (< 2/day or < 2 min)	Reference		
		Good (≥ 2/day and ≥ 2 min)	0.478 [0.336-0.683]		
		Background		0.046	
		Native	Reference		
		Migrant	1.453 [1.003-2.092]		
		Income		< 0.001	
		Below-average (< 2750 €)	Reference		
		Above-average (≥ 2750 €)	0.539 [0.371-0.773]		
	Prevalence of caries experience (d_{3-6}mft > 3)	BMI	1.019 [1.009-1.034]	0.001	
		Age	1.085 [1.194-1.446]	< 0.001	
		BEWE score	0.882 [0.450-0.811]	0.001	
		Toothbrushing habits		0.017	
		Poor (< 2/day or < 2 min)	Reference		
		Good (≥ 2/day and ≥ 2 min)	0.484 [0.395-0.916]		
		Frequency of cariogenic beverages	2.230 [1.186-2.889]	0.008	
		Toothbrushing			
		Only manual toothbrush	Reference		
		Only electric toothbrush	1.340 [0.571-1.524]	0.037	
		With electric and manual toothbrush	0.286 [0.355-0.870]	0.011	
		Background		0.003	
		Native	Reference		
		Migrant	1.889 [1.247-3.017]		
		Income		< 0.001	
		Below-average (< 2750 €)	Reference		
		Above-average (≥ 2750 €)	0.303 [0.228-0.601]		
	Severity (ICDAS)	BEWE-value of the tooth		< 0.001	−0.179
		Toothbrushing habits		< 0.001	
		Poor (< 2/day or < 2 min)			Reference
		Good (≥ 2/day and ≥ 2 min)			−0.248
		Number of siblings		< 0.001	0.118
		Background		< 0.001	
		Native			Reference
		Migrant			0.277
		Income		0.025	
		Below-average (< 2750 €)			Reference
		Above-average (≥ 2750 €)			−0.135
Children with primary teeth	Prevalence of caries experience (d_{1-6}mft > 0)	Toothpaste fluoride concentration according to with the recommendations of the German Society of Dental, Oral and Craniomandibular Sciences (DGZMK) [52]		0.003	
		age-appropriate or higher	Reference		
		lower than recommended	3.595 [1.549-8.683]		
		Income		0.021	
		Below-average (< 2750 €)	Reference		
		Above-average (≥ 2750 €)	0.362 [0.150-0.849]		
	Prevalence of caries experience (d_{3-6}mft > 3)	Toothpaste fluoride concentration according to with the recommendations of the German Society of Dental, Oral and Craniomandibular Sciences (DGZMK) [52]		0.015	
		age-appropriate or higher	Reference		
		lower than recommended	2.935 [1.257-7.201]		
		Income		0.003	
		Below-average (< 2750 €)	Reference		
		Above-average (≥ 2750 €)	0.260 [0.103-0.614]		
	Affected teeth per patient (%, d_{1-6}mft > 0)	Age		0.006	0.028
	Affected teeth per patient (%, d_{3-6}mft > 3)	Age		0.023	0.020
		Number of siblings		0.043	0.038
	Severity (d_{1-6}mft > 0)	Age		0.027	0.194
	Severity (d_{3-6}mft > 3)	None			

(*continued on next page*)

Table 4 (*continued*)

		Independent variables	OR [95% CI]	p-value	Estimate
Permanent teeth	Prevalence of caries experience (D$_{1-6}$MFT > 0)	BMI	1.013 [1.004-1.022]	0.006	
		Age	1.100 [1.056-1.142]	< 0.001	
		Gender		< 0.001	
		Male gender	Reference		
		Female gender	1.374 [1.181-1.764]		
		Patient	0.996 [0.994-0.999]	< 0,001	
		Frequency of cariogenic beverages	1.273 [1.022-1.641]	< 0,001	
		Number of siblings	1.109 [1.008-1.190]	0.015	
		Background		< 0.001	
		Native	Reference		
		Migrant	1.531 [1.195-1.907]		
		Income		< 0.001	
		Below-average (< 2750 €)	Reference		
		Above-average (≥ 2750 €)	0.658 [0.535-0.840]		
	Prevalence of caries experience (D$_{3-6}$MFT > 3)	Age	1.266 [1.121-1.359]	< 0.001	
		Number of siblings	1.478 [1.176-1.631]	< 0.001	
		Background		0.017	
		Native	Reference		
		Migrant	1.614 [1.098-3.083]		
		Income		0.007	
		Below-average (< 2750 €)	Reference		
		Above-average (≥ 2750 €)	0.347 [0.244-0.782]		
	Severity (ICDAS)	Age		< 0.001	0.010
		Patient		< 0.001	0.001
		Gender		< 0.001	
		Male gender			Reference
		Female gender			0.053
		Frequency of cariogenic beverages		0.003	0.056
		Toothbrushing with electric and hand toothbrush			
		Only manual toothbrush			Reference
		Only electric toothbrush		> 0.05	0.0132
		With electric and manual toothbrush		0.014	0.0445
		Background		< 0.001	
		Native			Reference
		Migrant			0.104
		Income		< 0.001	
		Below-average (< 2750 €)			Reference
		Above-average (≥ 2750 €)			−0.074
Children with permanent teeth	Prevalence of caries experience (D$_{1-6}$MFT > 0)	BMI	1.027 [1.008-1.049]	0.007	
		Age	1.273 [1.126-1.454]	< 0.001	
		Background		0.038	
		Native	Reference		
		Migrant	2.812 [1.102-7.952]		
		Income		0.011	
		Below-average (< 2750 €)	Reference		
		Above-average (≥ 2750 €)	0.382 [0.180-0.795]		
	Prevalence of caries experience (D$_{3-6}$MFT > 3)	Age	1.315 [1.137-1.545]	< 0.001	
		Number of siblings	1.431 [1.031-2.018]	0.034	
		Income		0.024	
		Below-average (< 2750 €)	Reference		
		Above-average (≥ 2750 €)	0.324 [0.114-0.820]		
	Affected teeth per patient (%, D$_{1-6}$MFT > 0)	BMI		0.044	0.001
		Age		< 0.001	0.017
		Gender		0.025	
		Male gender			Reference
		Female gender			0.047
		Number of siblings		0.024	0.021
	Affected teeth per patient (%, D$_{3-6}$MFT > 3)	Age		0.002	0.003
		Number of siblings		< 0.001	0.010
		Migrant background		0.021	0.019
		Income		0.025	
		Below-average (< 2750 €)			Reference
		Above-average (≥ 2750 €)			−0.015
	Severity (D$_{1-6}$MFT > 0)	BMI		0.019	0.037
		Age		< 0.001	0.754
		Gender		0.029	
		Male gender			Reference
		Female gender			1.312
	Severity (D$_{3-6}$MFT > 3)	Age		< 0.001	0.341
		Number of siblings		< 0.001	0.357

based on the ATP-III-criteria (at least three components present). Definition of income classification was based on the monthly family income distribution in Germany [27].

2.3. Statistical analysis

Sample size calculation was based on one study reporting prevalence rates of erosive tooth wear in children with normal weight (40.1%) and obesity (83.6%) [18]. Assuming $\alpha = 0.05$ and a targeted power of 80%, Chi^2-test revealed a sample size of 23 per group (4 groups: normal weight, overweight, obese and extremely obese; (http://biomath.info/power/chsq.htm).

Prevalence of erosive tooth wear and caries experience were determined in primary and permanent teeth ("tooth level") and compared between children with normal weight, overweight, obesity and extreme obesity using Chi^2-tests with Bonferroni correction. Prevalence of erosive tooth wear and caries experience were additionally determined on a subject level, separately for children presenting deciduous teeth (primary and mixed dentition) and presenting permanent teeth (mixed and permanent dentition), and compared between children with normal weight, overweight, obesity and extreme obesity using Chi^2-tests with Bonferroni correction.

To analyze severity of erosive tooth wear, the highest BEWE score for each tooth was determined; the BEWE sum score was calculated by adding the highest score of each sextant. Severity of erosive tooth wear (BEWE score per tooth, BEWE score sum per patient) and percentage of affected teeth were statistically compared among the groups (normal weight, overweight, obesity and extreme obesity) using Kruskal-Wallis test with post-hoc analysis.

The ICDAS-values were transformed into DMFT/dmft considering also filled teeth or missing teeth due to caries. ICDAS scores were analyzed according to two different cut-off-points: D/d_1 (0-healthy/1-6-caries) and D/d_3 (0-2-healthy/3–6-caries), representing the D/d of DMFT/dmft. DMFT/dmft and percentage of affected teeth per patient were compared among the groups using Kruskal-Wallis test with post-hoc analysis.

To identify the possible influence of BMI percentiles and other factors (demographic information, eating habits, oral hygiene, fluoride supply and details of medical history) on prevalence and severity of erosive tooth wear and caries experience, logistic (severities) and linear (affected teeth, BEWE score (sum), ICDAS, dmft/DMFT) stepwise regressions were performed (stepAIC, $p < 0.05$).

To determine a possible association between erosive tooth wear and caries experience Chi^2-tests (prevalence to prevalence) and Spearman correlations (severity to severity) were performed, separately for the group with normal weight/overweight and (extreme) obesity, respectively. Interpretation of correlation coefficients were performed accordingly to Cohen [28].

The overall significance level was set on $\alpha = 0.05$. All analyses were performed using the software R (version 3.2.2, www.r-project.com).

3. Results

A total of n = 223 children (112 female, 4–17 years, mean age: 10.2 ± 3.4 years, n = 16 in primary dentition, n = 124 in mixed dentition, n = 83 in permanent dentition) were included in the present study. In total, 140 children (71 female, mean age: 8.3 ± 2.6 years) presented primary teeth (n = 1476) and 207 patients (105 female, mean age: 10.6 ± 3.1 years) permanent teeth (n = 4110). Fifty-three children were classified as normal weight (23.8%), 27 as overweight (12.1%), 92 as obese (41.3%) and 51 as extremely obese (22.9%).

3.1. Erosive tooth wear

In primary and permanent teeth, prevalence and severity of erosive tooth wear were higher in children with (extreme) obesity compared to

children with normal weight. Considering erosive tooth wear on a subject level, prevalence, severity and percentage of affected teeth were significantly increased in (extremely) obese children with permanent teeth (Table 1).

Analyses of potential risk factors revealed that higher BMI and the presence of metabolic syndrome (as a co-morbidity of obesity) increased the risk for erosive tooth wear in primary as well as in permanent teeth. Moreover, higher age, male gender, the consumption of erosive snacks and beverages were identified as main risk factors (Table 2).

3.2. Dental caries

In primary teeth, caries prevalence was significantly increased in children with obesity and extreme obesity compared to normal weight children. In permanent teeth, caries prevalence was significantly higher in children with obesity and extreme obesity only when D1 was considered as cut-off point. On a subject level, caries experience, severity (dmft) and percentage of affected teeth were slightly, but not significantly increased in children with obesity and extreme obesity compared children with normal weight, when primary teeth were considered. When children with permanent teeth were considered, prevalence, severity (DMFT) and percentage of affected teeth were significantly increased in children with obesity and extreme obesity (D_{1-6}MFT, Table 3).

Higher BMI, older age, socio-economic factors, like a below-average income or migration background as well as poor toothbrushing habits and consumption of cariogenic beverages were identified as risk factors (Table 4).

3.3. Association between erosive tooth wear and caries

When considering primary teeth both on a subject and on a tooth level, weak inverse associations between erosive tooth wear and caries were found in children with (extreme) obesity. Only one significant association with a very small correlation coefficient ($r_{Sp} = -0.084$) was found in normal and overweight children (Table 5).

When considering permanent teeth both on a subject as well as on a tooth level, positive associations between erosive tooth wear and caries were found in children with (extreme) obesity. In normal and overweight children, a very weak inverse association between erosive tooth wear and caries on a tooth level was found (Table 5).

4. Discussion

Erosive tooth wear and caries experience were found to be affected by body weight and to be more prevalent in children with (extreme) obesity.

Patients with any co-morbidity potentially affecting oral hygiene or with diseases or medication affecting salivary flow were excluded from the study to obviate possible confounders. The clinical examination of the participants was performed as 'fullmouth recording' study based on indices being internationally recommended for dental health surveys [19,29]. Intra- and inter-examiner reliabilities were moderate to high and confirmed the reproducibility of the measurements. As children were in primary, mixed or permanent dentition, some of the children showed only primary or permanent teeth while most showed a variable number of primary and permanent teeth. To meet the requirements of this complexity of our data, statistical analyses were performed on a tooth- and on a subject-level. Furthermore, in regression analysis on tooth level, the factor "patient" was supplemented. In some cases, this factor was found to be significant (f.e. severity of erosive tooth wear in permanent teeth, see Table 2). Thus, some kind of patient based influence factor(s), which has not been surveyed in the present study, seem(s) to have a week influence on the severity of these lesions.

Potential dietary risk factors were obtained from self-reported

Table 5

Correlations (p-values, r_{Sp}: Spearman correlation coefficient, Φ: phi-coefficient) between prevalence/ severities of caries and erosive tooth wear on tooth and patient level in normal and overweight children and in children with (extreme) obesity.

		Variable	Normal and overweight children	Children with (extreme) obesity
Primary teeth	Prevalence of erosive tooth wear	Caries experience ($d_{1\text{-}6}$mft > 0)	p > 0.05	p > 0.05
		Caries experience ($d_{3\text{-}6}$mft > 0)	p > 0.05	p > 0.05
		Caries prevalence ($d_{1\text{-}6}$ > 0)	p > 0.05	p < 0.001, Φ = 0.139*
		Caries prevalence ($d_{3\text{-}6}$ > 0)	p > 0.05	p > 0.05
	Severity (BEWE score)	Severity (ICDAS)	p = 0.037, r_{Sp} = −0.084	p < 0.001, r_{Sp} = −0.144
Children with primary teeth	Prevalence of erosive tooth wear	Caries experience ($d_{1\text{-}6}$mft > 0)	p > 0.05	p > 0.05
		Caries experience ($d_{3\text{-}6}$mft > 0)	p > 0.05	p = 0.036, Φ = 0.244*
		Caries prevalence ($d_{1\text{-}6}$ > 0)	p > 0.05	p > 0.05
		Caries prevalence ($d_{3\text{-}6}$ > 0)	p > 0.05	p = 0.034, Φ = 0.244*
	Severity (BEWE score sum)	$d_{1\text{-}6}$mft	p > 0.05	p > 0.05
		$d_{3\text{-}6}$mft	p > 0.05	p > 0.05
		Affected teeth per patient (%, $d_{1\text{-}6}$mft)	p > 0.05	p > 0.05
		Affected teeth per patient (%, $d_{3\text{-}6}$mft)	p > 0.05	p > 0.05
Permanent teeth	Prevalence of erosive tooth wear	Caries experience ($D_{1\text{-}6}$MFT > 0)	p = 0.008, Φ = 0.077	p = 0.009, Φ = 0.050
		Caries experience ($D_{3\text{-}6}$MFT > 0)	p > 0.05	p < 0.001, Φ = 0.262
		Caries prevalence ($D_{1\text{-}6}$ > 0)	p < 0.001, Φ = 0.132	p < 0.001, Φ = 0.110
		Caries prevalence ($D_{3\text{-}6}$ > 0)	p > 0.05	p < 0.001, Φ = 0.248
	Severity (BEWE score)	Severity (ICDAS)	p > 0.05	p > 0.05
Children with permanent teeth	Prevalence of erosive tooth wear	Caries experience ($D_{1\text{-}6}$MFT > 0)	p > 0.05	p > 0.05
		Caries experience ($D_{3\text{-}6}$MFT > 0)	p > 0.05	p = 0.005, Φ = 0.267
		Caries prevalence ($D_{1\text{-}6}$ > 0)	p > 0.05	p > 0.05
		Caries prevalence ($D_{3\text{-}6}$ > 0)	p > 0.05	p > 0.05
	Severity (BEWE score sum)	$D_{1\text{-}6}$MFT	p > 0.05	p > 0.05
		$D_{3\text{-}6}$MFT	p > 0.05	p = 0.005, r_{Sp} = 0.243
		Affected teeth per patient (%,$D_{1\text{-}6}$MFT)	p > 0.05	p > 0.05
		Affected teeth per patient (%,$D_{3\text{-}6}$MFT)	p > 0.05	p = 0.009, r_{Sp} = 0.222

*inverse correlation.

questionnaires, having in mind that the reliability of dietary reporting is affected by misreporting, especially in patients with obesity. Potential underreporting of energy intake, as often seen in children and adults, might affect the analysis of diet-disease associations [30,31]. Especially in case of being patient of the out-patient obesity clinic, children (and proxies/parents) might be reporting according to the expected instead of the real dietary intake. Potentially, some children had already changed their diets with regard to obesity treatment, so that the history of dietary intake contributing to erosive tooth wear or caries might be not recorded.

Another major limitation of this study is that no analysis of saliva could be performed, as most of the younger children were unable to donate saliva in a standardized manner. Salivary flow and composition might be altered in children with obesity [32,33] and present a significant co-factor in the development of erosive tooth wear and caries [34,35].

Concerning the external validity of the study, it should be considered that the sample population consists of in- and out-patients of a Department of Pediatrics and Adolescent Medicine, therefore generalizability of the findings of the present study is limited. Furthermore, generalizability of the study might be further reduced because of non-controlled selection bias as participation in the study was voluntary.

Previous studies have shown that volunteer participants sometimes show different behavior than people who refuse participation [38]. However, the overall prevalence of erosive tooth wear found in this study is in good accordance to other studies conducted in Germany, where 52% (4–6 years old) [25] to 71% (mean age: 11.4 years) [36] of children with primary teeth and 12% (mean age: 11.4 years) [36] or 18% (12 year olds) [37] of children with permanent teeth were shown to be affected by erosive tooth wear. Severity of erosive tooth wear in children with primary (3.4 ± 3.1) or permanent (0.4 ± 1.3) teeth is also comparable to recently published studies [25,37].

The prevalence and severity of erosive tooth wear in primary and permanent teeth were significantly increased in children with obesity and extreme obesity compared to children with normal weight. On a subject level, prevalence, severity and percentage of affected teeth were significantly increased only when permanent teeth of children with obesity and extreme obesity were considered. However, the overall severity of erosive tooth wear accordingly to the BEWE risk levels [19] was very low, especially in permanent teeth, and requires only preventive rather than restorative management. Higher BMI and the presence of metabolic syndrome (as co-morbidity of obesity) were identified as risk factors for erosive tooth wear. As already demonstrated in previous studies, erosive tooth wear was also affected by age

[25,39,40], gender [25,41] and the consumption of erosive snacks and beverages [42]. Occasionally, oral hygiene factors and socioeconomic factors were also found to affect erosive tooth wear, but showed inconsistent results.

Caries experience of children with normal weight (subject prevalence: primary teeth: 50.0%, permanent teeth: 34.8%) reflects the results of two recent national German studies: The proportion of children with caries experience amounted to 50% in 6 to 7-year-old children (primary dentition) and 34.5% [43] in 12-year-old children (permanent teeth). Severity of caries diagnosed at the caries into dentin threshold amounted to 1.78 (primary teeth) [43] and 0.44 [43] to 0.5 [37], respectively.

As shown in three previous studies conducted in German children [7,44,45], caries experience was significantly associated with weight in both primary and permanent teeth. On subject level children with primary teeth presented higher caries experience, severity and percentage of affected teeth in children with obesity and extreme obesity compared to children with normal weight, but this difference was not significant. In children with permanent teeth, caries experience was significantly higher in subjects with obesity and extreme obesity only when D1 was considered as cut-off point, indicating that prevalence of initial caries lesions but not of advanced lesions of permanent teeth is different among the groups. Besides BMI, the statistical analysis identified higher age, low socioeconomic status, poor oral hygiene and consumption of cariogenic beverages as typical risk factors, which is in accordance to previous studies [5,6,37,45].

Erosive tooth wear and caries have some etiological factors in common, such as the high-consumption of soft drinks, certain dietary habits and quantitative and qualitative alterations of saliva, which indicates that both diseases might be correlated. However, cross-sectional studies investigating a potential association between erosive tooth wear and caries in children found contradictory results: while some studies reported a significant association [46–49], others did not [50,51]. The present study found only very few, probably negligible, associations between erosive tooth wear and caries in normal and overweight children. In children with (extreme) obesity, a weak association between erosive tooth wear and caries was found. In primary teeth, erosive tooth wear and caries showed an inverse relationship and decreasing ICDAS-values were identified as significant risk factor for erosive tooth wear. In contrast, erosive tooth wear and caries were positively associated in permanent teeth. These differences cannot be explained so far and require further investigation.

5. Conclusion

Higher body weight of children and adolescents is significantly associated with a higher risk for erosive tooth wear and caries. Erosive tooth wear and caries were weakly correlated in children with (extreme) obesity.

Declaration of interest

The authors declare that there is no conflict of interest.

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