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Asthma, long-term asthma control medication and tooth wear in American adolescents and young adults

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ABSTRACT

Objective: This study explored the associations of asthma and long-term asthma control medication with tooth wear among American adolescents and young adults.

Methods: Data from 2186 participants of the National Health and Nutrition Examination Survey (NHANES) were used. Asthma and prescribed long-term medication were collected through questionnaires. The number of surfaces with tooth wear was determined during clinical examinations. Associations were tested in Hurdle regression models adjusting for confounders.

Results: The prevalence of tooth wear was 58%, with an average of 6.1 (SD: 4.0) surfaces affected among those with the condition. The prevalence of asthma was 10.3%, with 2.9% of participants using long-term medication for asthma control. In the adjusted regression model, asthma was not associated with tooth wear. However, long-term control medication was associated with greater odds of having tooth wear (odds ratio: 3.33; 95%CI: 1.24-8.97), but it was not associated with the number of surfaces with tooth wear among those with the condition (rate ratio: 1.01; 95% CI: 0.58-1.75).

Conclusion: This cross-sectional analysis of national data shows that taking long-term asthma medication was positively associated with having tooth wear.

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Asthma; adrenergic beta-agonists; tooth wear; adolescent; young adult

Introduction

The evidence on the association between asthma and tooth wear is still controversial (1,2). Earlier hospital-based studies (3–6) and small community-based surveys (7,8) reported a positive association between asthma and tooth wear. However, most studies were descriptive and did not control for confounders (3–6,8). The strongest evidence to date comes from a 2-year longitudinal study among 12-year-olds in England. That study showed that asthma was not associated with either prevalence or incidence of tooth wear (9). However, the authors only presented descriptive results (i.e. no control for confounders was attempted) and did not explore the role of asthma medication in tooth wear.

There are two potential mechanisms by which asthma could be associated with erosive tooth wear. One possible explanation is the bidirectional association between asthma and gastro-esophageal reflux disease (GERD) (10,11). GERD may cause asthma through the micro-aspiration of gastric content that

damages the lining of airways, making them more reactive to irritants (12,13). In addition, acid stimuli in the distal esophagus might lead to bronchial symptoms via vagally mediated reflexes owing to the similar embryological origin and neural innervation of the esophagus and bronchial tree (13,14). On the other hand, asthma and asthma medication can also trigger GERD. Lung hyperinflation and increased work of breathing seen in asthmatic individuals increase the pressure gradient between thorax and abdomen and cause the gastroesophageal sphincter to become lax or herniate, thus fostering acid reflux (15). Long-acting beta-agonists and methylxanthine bronchodilators (such as theophylline) relax smooth muscles, including the gastroesophageal sphincter (15,16).

A second potential mechanism is the use of long-term asthma control medications. Many inhalers result in a drop in intraoral pH immediately upon use (17). Dry powder inhalers are more acidic than metered dose inhalers, with potential to cause greater drops in salivary and plaque pH (18,19). As frequency

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of acid challenges is a known risk factor in dietary tooth wear progression (17), this would increase susceptibility to acid challenges. Finally, long-acting beta-agonists can affect the amount and quality of saliva (20,21). Reduced salivary flow or quality induced by asthma medication could affect the proteins and chemical composition in the salivary pellicle which has been shown to have a role in protection against erosive tooth wear (22). In addition, those with reduced salivary flow may increase consumption of drinks to compensate (7). Most beverages apart from water and milk are low in pH and acidic (23). The present study will advance the area on two fronts. First, it will use a large national sample to test our hypotheses. Second, it will provide a stringent control for known risk factors for tooth wear, such as GERD and soft drinks, which, as described above, are associated with both asthma medication and tooth wear. Therefore, this study explored the associations of asthma and long-term asthma control medication with tooth wear among Americans. We focused on adolescents and young adults because asthma is more common in these age groups (24,25).

Methods

Study population

This study used data from the National Health and Nutrition Survey (NHANES) 2003-2004, a national survey conducted by the Center for Disease Control and Prevention (CDC) to represent the civilian, non-institutionalized population residing in the 50 United States and the District of Columbia (26). The NHANES 2003-2004 is the latest national US survey that collected information on tooth wear, as part of a comprehensive oral examination. As such, it provided an opportunity to test our hypotheses using national data. Participants were selected via stratified multi-stage probability sampling. The following groups were oversampled for the survey: Mexican Americans, Non-Hispanics Blacks, adolescents (12-19 years old) and senior adults (60 years or older) (26). Data were collected through home interviews, clinical examinations and self-administered questionnaires. Of the 2937 participants aged 13-29 years, 2676 were clinically examined for tooth wear. Of them, 490 were excluded due to missing data on asthma ($n=5$) and covariates (soft drinks = 284, income = 159, dental insurance = 126, GERD medication = 5). Therefore, the study sample consisted of 2186 participants.

Selected variables

The outcome variable was the number of surfaces with tooth wear. A modified version of the Tooth Wear Index (TWI) was used (27). The buccal, lingual and incisal surfaces of the 12 anterior teeth (36 surfaces) and occlusal surfaces of all first molars (4 surfaces) were visually examined and graded. The threshold to define tooth wear for this analysis was the loss of enamel just exposing dentin (i.e. codes 1, 2 and 3 in the TWI). Tooth wear examinations were carried out by two trained and calibrated examiners. The inter-reliability agreement was 87.7% and Kappa was 0.80 (26).

The exposures were asthma and long-term asthma control medication. Asthma was determined with two questions ("has a doctor or health professional ever told you that you have asthma?" and "do you still have asthma?"). Participants with affirmative responses to both questions were regarded as asthmatic. Participants also reported any long-term medications for asthma control prescribed in the past month. Answers were confirmed against the medication container (if available). The following long-term asthma control medications were included: inhaled corticosteroids, long-acting beta-agonists and leukotriene modifiers. No prescriptions for methylxanthines were found in the study sample. Long-term asthma medications were identified using the drug codes and names in the [supplemental file](#).

Demographic characteristics (sex, age and race/ethnicity), socioeconomic status (education and poverty income ratio), GERD and behaviors (soft drink intake and dental insurance) were included as potential confounders of the association between asthma and tooth wear. Dental insurance was based on two questions ("are you covered by health insurance or some kind of health plan?" and "does the insurance cover any part of dental care?"). Participants with positive responses to both questions were considered as insured. Daily intake of carbonated soft drinks was derived from two 24-h diet recalls undertaken by trained interviewers. The first was done in person after the clinical examination and the second was done over the phone 3 to 10 days later. The food codes used to identify soft drinks are shown in the [supplemental file](#). The variable represents the average number of drinks consumed over the two days (28). GERD was not measured in NHANES. However, anti-reflux medication was used as a proxy for GERD, which was determined from two complementary sources. Participants reported if they had taken any anti-acid medication (including those prescribed by a

Table 1. Comparison of characteristics between participants in the study sample and participants excluded because of missing data.

Explanatory variables	Excluded (<i>n</i> = 490)		Study sample (<i>n</i> = 2186)		<i>p</i> value
<i>Sex, n^a %</i>					0.160
Men	110	59.5	1061	50.1	
Women	97	40.5	1125	49.9	
<i>Age in years, Mean ± SD</i>	21.1 ± 3.6		20.6 ± 4.9		0.467
<i>Race and ethnicity, n^a %</i>					0.738
Non- Hispanic White	75	69.7	735	64.6	
Non- Hispanic Black	67	11.9	673	14.0	
Hispanic	58	13.9	692	15.5	
Mixed/Others	7	4.6	86	5.9	
<i>Education, n^a %</i>					0.009
Less than high school	115	24.5	1467	44.8	
High school	41	30.5	280	18.6	
More than high school	51	45.0	439	36.6	
<i>Poverty income ratio, n^a %</i>					0.151
≤100%	40	39	670	20.6	
101-200%	19	26.2	582	24.2	
201-300%	8	5.9	327	17.5	
301-400%	10	16.3	220	13	
≥401%	5	12.6	387	24.7	
<i>Dental insurance</i>					0.118
Uninsured	48	53.9	776	39.6	
Insured	58	46.1	1410	60.4	
<i>GERD medication</i>					0.629
None	186	89.8	2009	88.4	
Over the counter only	15	9.6	151	10.2	
Prescribed	3	0.6	26	1.4	
<i>Asthma diagnosis</i>					0.201
No	187	94.0	1954	89.7	
Yes	15	6.0	232	10.3	
<i>Daily intake of soft drinks, Mean ± SD</i>	1.2 ± 0.8		1.1 ± 0.9		0.600
<i>Surfaces with tooth wear, Mean ± SD</i>	3.9 ± 4.1		3.6 ± 4.5		0.649

^aCounts are unweighted.

SD: standard deviation; GERD: gastroesophageal reflux disease.

health professional and those that do not require a prescription) in the past month. Prescribed drugs were confirmed against the medication container (if available). The codes to identify prescribed medications are in the [supplemental file](#). GERD medication was classified as none, over the counter only and prescribed (29).

Statistical analysis

All analyses were carried out with Stata 15 (Stata Corp, College Station TX, USA). Analyses accounted for the survey design and were weighted to produce nationally representative estimates. We first compared participants in the study sample with those excluded due to missing values on relevant variables to assess the impact of missing data. The Chi-squared test was used to compare categorical variables and Student's *t*-test to compare numerical variables (age and soft drinks intake).

The associations of asthma and long-term medication with tooth wear were examined in Hurdle regression models (28,29). The Hurdle model was preferred because data were over-dispersed (variance higher than the mean) and had a large proportion of zero

values (30,31). The Hurdle model yielded two sets of estimates. The first set was derived from a logistic regression model for the probability of having tooth wear (non-zero values) in the full sample. The second set was derived from a negative binomial regression model for the mean number of surfaces with tooth wear among those with the condition (truncated count). Negative binomial regression was preferred over Poisson regression because it yielded better goodness-of-fit statistics (lower Akaike and Bayesian information criteria values). The logistic portion of the Hurdle model was reported using odds ratios (ORs), which measured the probability of having tooth wear. The negative binomial portion of the Hurdle model was reported using rate ratios (RRs), which measured the relative difference in number of surfaces affected between the two groups being compared, but only among those with tooth wear. The modeling strategy was to include all theoretically relevant variables, regardless of their statistical significance, in the regression model. The estimates for the associations of asthma and long-term medication with tooth wear were adjusted for sex, age, race/ethnicity, education, poverty income ratio, dental insurance, intake of soft drinks and GERD medication. The interactions of

Table 2. Proportion of participants with asthma and long-term medication according to their sociodemographic characteristics ($n = 2186$).

	Asthma			Asthma medication		
	n^a	%	p value ^c	n^a	%	p value ^c
Sex			0.116			0.639
Men	100	8.2		31	2.5	
Women	132	12.5		30	3.3	
Age groups^b			0.181			0.134
13-14 years	55	9.9		20	2.7	
15-19 years	122	11.6		33	5.4	
20-24 years	28	6.5		5	1.8	
25-29 years	27	13.6		3	1.5	
Race/ethnicity			0.264			0.304
Non-Hispanic White	70	9.8		27	3.5	
Non-Hispanic Black	88	12.3		18	1.3	
Hispanic	64	7.5		14	2.5	
Mixed/Others	10	18.4		2	1.3	
Education			0.939			0.320
Less than high school	168	10.7		50	4.1	
High school	23	9.9		4	2.0	
More than high school	41	10.1		7	1.8	
Poverty income ratio			0.692			0.764
≤100%	78	12.2		18	3.1	
101-200%	50	11.4		12	2.3	
201-300%	36	11.5		7	2.0	
301-400%	26	9.0		6	2.7	
≥401%	42	7.6		18	4.0	
Dental insurance			0.005			0.173
Uninsured	59	6.0		8	1.5	
Insured	173	13.2		53	3.8	
Daily intake of soft drinks^b			0.639			0.945
None	55	8.1		12	2.9	
1 drink/day	106	10.5		30	3.1	
2+ drinks/day	71	11.3		19	2.7	
GERD medication			0.317			<0.001
None	207	10.7		53	2.6	
Over the counter only	21	7.8		4	2.5	
Prescribed	4	2.9		4	26.9	

^aCounts are unweighted.^bCategories chosen for presentation purposes only.^cChi-squared test used for comparisons.

asthma and long-term medication with GERD medication was tested by adding it as a product term to the regression model.

Results

Data from 2186 adolescents (13-19 years old) and young adults (20-29 years old) were analyzed. No differences between participants in the study sample and those excluded because of missing values on the variables chosen for analysis were found, except for education (Table 1). There were fewer participants with high school education or above in the study sample than in those excluded. The prevalence of tooth wear was 58% ($n = 1068$), with an average of 6.1 (SD: 4.0) surfaces affected among those with the condition. Furthermore, 10.3% ($n = 232$) of participants had asthma and 2.9% ($n = 61$) of participants reported taking long-term medication. More specifically, 2.4% ($n = 48$), 1.3% ($n = 25$) and 0.5% ($n = 21$) took inhaled

Table 3. Regression model for the associations of asthma, asthma medication and number of surfaces with tooth wear among American adolescents and young adults ($n = 2186$).

Explanatory variables	Logit portion		NB portion	
	OR ^a	[95% CI]	RR ^a	[95% CI]
Sex				
Men	1.00	[Reference]	1.00	[Reference]
Women	0.53	[0.38-0.73]**	0.79	[0.70-0.90]**
Age, in years	1.10	[1.05-1.14]***	1.04	[1.03-1.06]***
Race/ethnicity				
Non-Hispanic White	1.00	[Reference]	1.00	[Reference]
Non-Hispanic Black	0.59	[0.29-1.21]	0.85	[0.68-1.06]
Hispanic	1.29	[0.73-2.25]	1.00	[0.76-1.30]
Mixed/Others	1.39	[0.64-3.01]	1.15	[0.91-1.46]
Education				
Less than high school	1.00	[Reference]	1.00	[Reference]
High school	1.10	[0.65-1.87]	1.06	[0.82-1.36]
More than high school	1.04	[0.59-1.83]	0.95	[0.72-1.26]
Poverty income ratio				
≤100%	1.00	[Reference]	1.00	[Reference]
101-200%	1.23	[0.73-2.05]	1.05	[0.75-1.47]
201-300%	1.47	[0.71-3.02]	0.99	[0.78-1.27]
301-400%	1.13	[0.51-2.52]	0.84	[0.63-1.11]
≥401%	1.25	[0.71-2.22]	0.84	[0.70-1.00]*
Dental insurance				
Uninsured	1.00	[Reference]	1.00	[Reference]
Insured	0.78	[0.56-1.08]	1.00	[0.90-1.11]
GERD medication				
None	1.00	[Reference]	1.00	[Reference]
Over the counter only	0.96	[0.44-2.10]	1.05	[0.86-1.30]
Prescribed	1.12	[0.49-2.55]	1.02	[0.56-1.86]
Daily intake of soft drinks	1.05	[0.83-1.34]	1.05	[0.98-1.13]
Asthma diagnosis				
No	1.00	[Reference]	1.00	[Reference]
Yes	0.66	[0.43-1.26]	1.23	[0.97-1.57]
Long-term asthma medication				
None	1.00	[Reference]	1.00	[Reference]
Any medication	3.33	[1.24-8.97]*	1.01	[0.58-1.75]

^aHurdle regression model was used. Odds ratios (OR) were reported for the logit portion and rate ratios (RR) for the negative binomial (NB) portion. ORs represent the probability of having tooth wear in a given group compared to the reference group (in the full sample). RRs represent how much higher/lower the mean number of surfaces with tooth wear is in one group than in the reference group (among those with tooth wear only).

* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$.

corticosteroids, leukotrienes and long-acting beta agonists, respectively.

Table 2 compared the proportion of asthmatic participants and of those taking long-term asthma control medication according to socio-demographic characteristics. The proportion of asthmatic participants was significantly higher (13.2% versus 6.0%) among those with than without dental insurance. Furthermore, the proportion of participants under long-term asthma control medication was significantly higher in those taking prescribed GERD medication than in those not taking it (26.9% versus 2.6%).

In the Hurdle regression model (Table 3), asthma was not associated with tooth wear. On the other hand, taking long-term asthma control medication was associated with greater odds of having tooth wear (OR: 3.33; 95% CI: 1.24-8.97), but taking medication

was not associated with the number of surfaces with tooth wear among those with the condition (RR: 1.01; 95% CI: 0.58–1.75). The interactions of asthma and long-term asthma medication with GERD medication were not significant.

Discussion

The present findings highlight the role of long-term medication for asthma control in tooth wear among adolescents and young adults. On one hand, asthma diagnosis was not associated with tooth wear. On the other hand, the use of long-term medication for asthma control was positively associated with the prevalence of tooth wear, but not with its severity (surfaces affected) among those already affected with tooth wear. The magnitude of this effect was such that individuals taking control medication were over three times more likely to have tooth wear than those not taking such medication.

These findings suggest that taking long-term asthma control medication might underlie the association between asthma and tooth wear. The fact that asthma medication was associated with the presence of tooth wear (prevalence) but not with the number of surfaces affected (severity) could reflect the stepwise approach to asthma management (32,33). The approach starts with a pre-set dose of drugs that is gradually adjusted till the minimum effective dose is found (i.e. the lowest treatment that controls both symptoms and exacerbations) (32). Unfortunately, no information on how long participants were exposed to medication was available in NHANES. Furthermore, the number of participants taking specific medications for asthma control was small to run analyses stratified by type of medication. Two of the three medications (long-acting beta-agonists and inhaled corticosteroids) included in our analysis have been associated with reductions in salivary flow rate and protein concentration (20,21), which might subsequently limit any preventive effect of saliva and the salivary pellicle on tooth wear. The third medication, leukotriene modifiers (including montelukast and zafirlukast among these participants), has not been previously connected with changes in dentition or saliva (34). They block some inflammatory responses mediated by leukotrienes, such as bronchoconstriction, heightened microvascular permeability and increased mucus secretion (33,35). Like with long-acting beta-agonists, it is possible that by relaxing smooth muscles they affect the tone of the lower esophageal sphincter (12–14).

Our finding of a non-significant association between asthma and tooth wear agrees with that of a previous longitudinal study (9), despite our adjustment for confounders. Confounding control is important because the factors that make an individual susceptible to tooth wear are likely to be multifactorial and may be increased in those taking asthma control medication. A two-way relationship between asthma and GERD has been reported in the literature (12–16). We found more participants under long-term asthma medication among those with prescribed medication for GERD than among those without such medication. However, no interaction between the two factors was identified, probably due to the few participants taking both medications simultaneously. Also, residual confounding could have occurred when using a proxy for GERD, which did not fully capture all GERD diagnoses (especially for participants with GERD but not taking medication). GERD can be asymptomatic, underdiagnosed and refluxate may not extend into the extra-esophageal space to warrant medication (12).

The present findings have implications for practice and future research. Dental professionals should be aware of a possible association between asthma medication and tooth wear and should look for evidence of tooth wear among asthmatic patients under long-term control medications. Further research should advance on the specific medications associated with tooth wear and potential mechanisms. Methylxanthines were not reported by participants in our study sample but are worth exploring. Like long-acting beta-agonists and leukotriene modifiers, they are suggested as a link between asthma and GERD by relaxing smooth muscles tone, including the gastroesophageal sphincter (12–14). Additional information on long-term asthma control medication should include the route of drug delivery (liquid, inhaler, nebulizer), frequency of drug administration and duration of treatment, which are important factors for tissue damages, especially in case of treatment of chronic conditions. Longitudinal studies measuring changes in asthma, medications and outcome as well as with a stringent control for confounders (GERD diagnosis) would be beneficial.

The use of data from a large population-based sample and the assessment of both asthma and asthma medication were the strengths of this study. However, some study limitations must be addressed. First, the data was cross-sectional. Although hypothesis driven, the identified associations should be interpreted as descriptive only as a clear temporal sequence between exposure and outcome cannot be established with

cross-sectional data. Second, some participants were excluded due to missing data on the variables chosen for analysis. Participants in the study sample were less educated than those excluded. Thus, some caution should be exerted when extrapolation the findings to the study population. Third, tooth wear was assessed on a subset of tooth surfaces only, which could be considered less accurate than a full-mouth examination. However, there is evidence that partial-mouth assessments are as valid as full-mouth assessments to replicate known associations with tooth wear (36). In addition, buccal surfaces of upper incisors and occlusal surfaces of lower first molars are those most commonly affected by tooth wear (36,37). Fourth, even though we adjusted for multiple confounders, they were all based on self-reports which might be prone to measurement error and introduce residual confounding.

In conclusion, this cross-sectional analysis of a large nationally representative sample of American adolescents and young adults found evidence that long-term asthma control medication was associated with greater odds of having tooth wear.

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Nothing to declare

Declaration of interest

The authors declare no conflict of interest in relation to this work.

References

1. Thomas MS, Parolia A, Kundabala M, Vikram M. Asthma and oral health: a review. *Aust Dent J*. 2010; 55(2):128–33. doi:10.1111/j.1834-7819.2010.01226.x.
2. Hellwig E, Lussi A. Oral hygiene products, medications and drugs - hidden aetiological factors for dental erosion. *Monogr Oral Sci*. 2014;25:155–62. doi:10.1159/000359942.
3. Al-Dlaigan YH, Shaw L, Smith AJ. Is there a relationship between asthma and dental erosion? A case control study. *Int J Paediatr Dent*. 2002;12(3):189–200. doi:10.1046/j.1365-263X.2002.00360.x.
4. Sivasitamparam K, Young WG, Jirattanasopa V, Priest J, Khan F, Harbrow D, Daley TJ. Dental erosion in asthma: a case-control study from south east Queensland. *Aust Dental J*. 2002;47(4):298–303. doi:10.1111/j.1834-7819.2002.tb00541.x.
5. Farag ZH, Awooda EM. Dental Erosion and Dentin Hypersensitivity among Adult Asthmatics and Non-asthmatics Hospital-based: A Preliminary Study. *TODENTJ*. 2016;10(1):587–93. doi:10.2174/1874210601610010587.
6. Struzycka I, Lussi A, Bogusławska-Kapala A, Rusyan E. Prevalence of erosive lesions with respect to risk factors in a young adult population in Poland-a cross-sectional study. *Clin Oral Invest*. 2017;21(7):2197–203. doi:10.1007/s00784-016-2012-z.
7. Shaw L, Al-Dlaigan YH, Smith A. Childhood asthma and dental erosion. *ASDC J Dent Child*. 2000;67(2):102–6, 82.
8. Rezende G, Dos Santos NML, Stein C, Hilgert JB, Faustino-Silva DD. Asthma and oral changes in children: Associated factors in a community of southern Brazil. *Int J Paediatr Dent*. 2019;29(4):456–63. doi:10.1111/ipd.12487.
9. Dugmore CR, Rock WP. Asthma and tooth erosion. Is there an association? *Int J Paediatr Dent*. 2003; 13(6):417–24. doi:10.1046/j.1365-263x.2003.00497.x.
10. Thakkar K, Boatright RO, Gilger MA, El-Serag HB. Gastroesophageal reflux and asthma in children: a systematic review. *Pediatrics*. 2010;125(4):e925–30. doi:10.1542/peds.2009-2382.
11. Havemann BD, Henderson CA, El-Serag HB. The association between gastro-oesophageal reflux disease and asthma: a systematic review. *Gut*. 2007;56(12):1654–64. doi:10.1136/gut.2007.122465.
12. Hom C, Vaezi MF. Extra-esophageal manifestations of gastroesophageal reflux disease: diagnosis and treatment. *Drugs*. 2013;73(12):1281–95. doi:10.1007/s40265-013-0101-8.
13. Naik RD, Vaezi MF. Extra-esophageal gastroesophageal reflux disease and asthma: understanding this interplay. *Expert Rev Gastroenterol Hepatol*. 2015; 9(7):969–82. doi:10.1586/17474124.2015.1042861.
14. Broers C, Tack J, Pauwels A. Review article: gastro-oesophageal reflux disease in asthma and chronic obstructive pulmonary disease. *Aliment Pharmacol Ther*. 2018;47(2):176–91. doi:10.1111/apt.14416.
15. McCallister JW, Parsons JP, Mastronarde JG. The relationship between gastroesophageal reflux and asthma: an update. *Ther Adv Respir*. 2011;5(2):143–50. doi:10.1177/1753465810384606.
16. Parsons JP, Mastronarde JG. Gastroesophageal reflux disease and asthma. *Curr Opinion in Pulmonary Med*. 2010;16(1):60–3. doi:10.1097/MCP.0b013e328332ca2f.
17. O'Toole S, Bernabe E, Moazzez R, Bartlett D. Timing of dietary acid intake and erosive tooth wear: A case-control study. *J Dent*. 2017;56:99–104. doi:10.1016/j.jdent.2016.11.005.
18. Tootla R, Toumba KJ, Duggal MS. An evaluation of the acidogenic potential of asthma inhalers. *Arch Oral Biol*. 2004;49(4):275–83. doi:10.1016/j.archoralbio.2003.11.006.
19. O'Sullivan EA, Curzon MEJ. Drug treatments for asthma may cause erosive tooth damage. *Brit Med J*. 1998;317(7161):820. doi:10.1136/bmj.317.7161.820.
20. Ryberg M, Möller G, Erigson T. Saliva composition and caries development in asthmatic patients treated with beta 2-adrenoceptor agonists: a 4-year follow-up study. *Eur J Oral Sci*. 1991;99(3):212–8. doi:10.1111/j.1600-0722.1991.tb01887.x.
21. Sag C, Ozden FO, Acikgoz G, Anlar FY. The effects of combination treatment with a long-acting beta2-agonist and a corticosteroid on salivary flow rate,

- secretory immunoglobulin A, and oral health in children and adolescents with moderate asthma: a 1-month, single-blind clinical study. *Clin Ther.* 2007; 29(10):2236–42. doi:[10.1016/j.clinthera.2007.10.014](https://doi.org/10.1016/j.clinthera.2007.10.014).
22. Mutahar M, O'Toole S, Carpenter G, Bartlett D, Andiappan M, Moazzez R. Reduced statherin in acquired enamel pellicle on eroded teeth compared to healthy teeth in the same subjects: An in-vivo study. *PLoS One.* 2017;12(8):e0183660. doi:[10.1371/journal.pone.0183660](https://doi.org/10.1371/journal.pone.0183660).
 23. Reddy A, Norris DF, Momeni SS, Waldo B, Ruby JD. The pH of beverages in the United States. *J Am Dent Assoc.* 2016;147(4):255–63. doi:[10.1016/j.adaj.2015.10.019](https://doi.org/10.1016/j.adaj.2015.10.019).
 24. Dharmage SC, Perret JL, Custovic A. Epidemiology of Asthma in Children and Adults. *Front Pediatr.* 2019; 7:246doi:[10.3389/fped.2019.00246](https://doi.org/10.3389/fped.2019.00246).
 25. Trivedi M, Denton E. Asthma in Children and Adults-What Are the Differences and What Can They Tell us About Asthma? *Front Pediatr.* 2019;7:256doi:[10.3389/fped.2019.00256](https://doi.org/10.3389/fped.2019.00256).
 26. Dye BA, Nowjack-Raymer R, Barker LK, Nunn JH, Steele JG, Tan S, Lewis BG, Beltran-Aguilar ED. Overview and quality assurance for the oral health component of the National Health and Nutrition Examination Survey (NHANES), 2003–04. *J Public Health Dent.* 2008;68(4):218–26. doi:[10.1111/j.1752-7325.2007.00076.x](https://doi.org/10.1111/j.1752-7325.2007.00076.x).
 27. Kelly M. Adult dental health survey: oral health in the United Kingdom 1998. London: The Stationery Office; 2000.
 28. Al-Zwaylif LH, O'Toole S, Bernabé E. Type and timing of dietary acid intake and tooth wear among American adults. *J Public Health Dent.* 2018;78(3): 214–20. doi:[10.1111/jphd.12264](https://doi.org/10.1111/jphd.12264).
 29. Kamal Y, O'Toole S, Bernabé E. Obesity and tooth wear among American adults: the role of sugar-sweetened acidic drinks. *Clin Oral Investig.* 2019. doi:[10.1007/s00784-019-03079-5](https://doi.org/10.1007/s00784-019-03079-5).
 30. Cameron AC, Trivedi PK. Regression analysis of count data. Cambridge: Cambridge University Press; 2013.
 31. Hilbe JM. Modelling count data. Cambridge: Cambridge University Press; 2014.
 32. Global Initiative for Asthma. Global Strategy for Asthma Management and Prevention. Available from: www.ginasthma.org. 2019.
 33. Tesse R, Borrelli G, Mongelli G, Mastroilli V, Cardinale F. Treating Pediatric Asthma According Guidelines. *Front Pediatr.* 2018;6:234. doi:[10.3389/fped.2018.00234](https://doi.org/10.3389/fped.2018.00234).
 34. Wolff A, Joshi RK, Ekström J, Aframian D, Pedersen AML, Proctor G, Narayana N, Villa A, Sia YW, Aliko A, et al. A Guide to Medications Inducing Salivary Gland Dysfunction, Xerostomia, and Subjective Sialorrhea: A Systematic Review Sponsored by the World Workshop on Oral Medicine VI. *Drugs R D.* 2017;17(1):1–28. doi:[10.1007/s40268-016-0153-9](https://doi.org/10.1007/s40268-016-0153-9).
 35. Scott JP, Peters-Golden M. Antileukotriene agents for the treatment of lung disease. *Am J Respir Crit Care Med.* 2013;188(5):538–44. doi:[10.1164/rccm.201301-0023PP](https://doi.org/10.1164/rccm.201301-0023PP).
 36. Martignon S, López-Macías AM, Bartlett D, Pitts N, Usuga-Vacca M, Gamboa LF, O'Toole S. The use of index teeth vs. full mouth in erosive tooth wear to assess risk factors in the diet: A cross-sectional epidemiological study. *J Dent.* 2019;88:103164. doi:[10.1016/j.jdent.2019.07.002](https://doi.org/10.1016/j.jdent.2019.07.002).
 37. Steele JG, Walls AW. Using partial recording to assess tooth wear in older adults. *Commun Dent Oral Epidemiol.* 2000;28(1):18–25. doi:[10.1034/j.1600-0528.2000.280103.x](https://doi.org/10.1034/j.1600-0528.2000.280103.x).

Supplemental Table 1. List of drug codes to identify long-term asthma medications

Drug group	Generic drug name	Drug code
Inhaled corticosteroids	Fluticasone	d01296
	Fluticasone Nasal	d04283
	Fluticasone Topical	d04284
	Azelastine; Fluticasone Nasal	d07868
	Flunisolide	d00761
	Flunisolide nasal	d04279
	Budesonide	d04276
	Budesonide Nasal	d03640
	Ciclesonide	d05465
	Ciclesonide Nasal	d05899
	Beclomethasone	d00760
	Beclomethasone Nasal	d04275
	Mometasone	d05262
	Mometasone Nasal	d04223
	Mometasone Topical	d01300
Leukotriene modifiers	Montelukast	d04289
	Zafirlukast	d04053
Long-acting beta agonists	Salmeterol	d03759
	Formoterol	d04572
	Arformoterol	d05893
Combination inhalers	Fluticasone; Salmeterol	d04611
	Budesonide; Formoterol	d04795
	Formoterol; Mometasone	d07660
	Fluticasone; Vilanterol	d08100
Methylxanthines	Guaifensin; Pseudoephedrine; Theophylline	h00017
	Guaifensin; Theophylline	d03273

Supplemental Table 2. List of food codes to identify carbonated soft drinks

Food code	Food item
92410110	Fruit flavors
92410110	Clearly Canadian
92410110	Mistic Sparkling Water Beverage with Fruit Flavor and Natural Spring Water
92410110	Penafiel, apple and sangria flavors
92410250	Diet Mistic Sparkling Water Beverage w/ Fruit Flavor & Natural Spring Water
92410310	Coca Cola
92410310	Coke
92410310	Pepsi
92410310	RC Cola
92410315	Coca-Cola C2
92410315	Pepsi Edge
92410320	Diet Coke
92410320	Diet Pepsi
92410330	Jolt Cola
92410330	Josta
92410340	Caffeine free Coke
92410340	Caffeine free Pepsi
92410340	Crystal Pepsi Clear Cola
92410350	Caffeine free Diet Coke
92410350	Caffeine free Diet Pepsi
92410350	Diet Crystal Pepsi Clear Cola
92410350	Diet Rite Cola
92410360	Dr. Pepper
92410360	Mr. Pibb
92410370	Diet Dr. Pepper
92410390	Caffeine free Dr. Pepper
92410400	Caffeine free Diet Dr. Pepper
92410410	Almond Smash
92410510	Orange
92410510	Lemon
92410510	Lime
92410510	Cherry
92410510	Grape
92410510	Strawberry
92410510	Tom Collins mixer
92410510	7-Up
92410510	Sprite
92410510	Minute Maid Orange Soda
92410510	Slice
92410510	Mandarin Orange Slice
92410510	Lemon Slice
92410510	Caffeine free Mountain Dew
92410510	7-Up, NS as to caffeine
92410510	Squirt
92410510	Orange Crush

92410510	Citra
92410510	Sierra Mist
92410520	Diet Minute Maid Orange Soda
92410520	Diet Slice
92410520	Diet Mandarin Orange Slice
92410520	Diet Lemon Slice
92410520	Diet Sprite
92410520	Diet 7-Up
92410520	Fresca
92410520	Diet 7-Up, NS as to caffeine
92410520	Diet Cherry 7-UP
92410520	Sierra Mist Free
92410550	Mellow Yellow
92410550	Mountain Dew
92410550	Big Red
92410550	7-Up Gold
92410550	Pepsi Tropical Chill
92410550	Sunkist Orange
92410550	Mountain Dew, NS as to caffeine
92410550	Ruby Red Squirt
92410550	Surge
92410560	Diet Mountain Dew
92410560	Diet 7-Up Gold
92410560	Diet Sunkist
92410620	Diet
92410720	Diet
92410820	Canfield's Diet Chocolate Fudge Soda
92411510	Cherry cola
92411510	Cherry Coke
92411610	Diet
92411610	Diet Cherry Coke
92417010	Ale-8
92433000	Combinations of citrus and noncitrus
92433000	Mistic Spring Water 'n Juice tropical supreme flavor
92433000	Mistic Spring Water 'n Juice black cherry flavor
92433000	Mistic Spring Water 'n Juice peach vanilla flavor
92433000	Mistic Spring Water 'n Juice wild berry juice flavor
92433000	Mistic Spring Water 'n Juice raspberry-boysenberry flavor
92433000	Mango passion flavor
92433000	Mystic Spring Water 'n Juice, NS as to Flavor

Supplemental Table 3. List of drug codes to identify prescribed GERD medications

Drug group	Generic drug name	Drug code
Antacids	Unspecified	c00088
H ₂ receptor blocker	Famotidine	d00141
	Nizatidine	d00322
	Ranitidine	d00021
	Cimetidine	d00140
	Ranitidine Bismuth Citrate	d04042
Proton pump inhibitors	Lansoprazole	d03828
	Omeprazole	d00325
	Esomeprazole	d04749
	Pantoprazole	d04514
	Rabeprazole	d04448
	Dexlansoprazole	d07395
	Amoxicilin; Clarithromycin; Lansoprazole	d04272
	Rabeprazole	d04448
	Aripirazole	d04825
	Lansoprazole; Naproxen	d04913
	Amoxicillin; Clarithromycin; Omeprazole	d05399
	Omeprazole; Sodium Bicarbonate	d05770
	Dexlansoprazole	d07395
	Esomeprazole; Naproxen	d07631
	Famotidine; Ibuprofen	d07764
Strengthen sphincter	Baclofen	d00967