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Associations between the number of natural teeth and metabolic syndrome in adults

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Abstract

Aim: To explore associations between the number of natural teeth and metabolic syndrome in adults.

Material and Methods: Cross-sectional data from the National Health and Nutrition Examination Survey 2005–2008 were used. Eligible adults (n = 5511) were classified into four groups by their number of natural teeth (excluding third molars): full dentition, 21–27 teeth, 1–20 teeth, or edentulous. Metabolic syndrome was defined by diagnostic guidelines from the American Heart Association and National Heart, Lung, and Blood Institute. Associations were analysed by survey logistic regression. Biometric and metabolic parameters in different dentition groups were compared.

Results: Adjusting for age, gender, race/ethnicity, ratio of family income to poverty, physical activity, smoking, and energy intake, tooth loss was significantly associated with metabolic syndrome (p = 0.002). Compared to participants with full dentition, the odds were 32% higher in those with 21–27 teeth, 55% higher in those with 1–20 teeth and 79% higher in edentulous participants. The number of natural teeth was inversely associated with body mass index, waist circumference, blood pressure, fasting plasma glucose and insulin concentrations (p < 0.01 for all); it was positively associated with serum HDL cholesterol concentration (p = 0.003).

Conclusions: The number of natural teeth is inversely associated with the presence of metabolic syndrome in adults.

Key words: dentition; epidemiology; metabolic syndrome; oral health; tooth loss

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Metabolic syndrome is a term referred to a group of conditions that raise the risk of cardiovascular disease, stroke, diabetes and all-cause mortality (Eckel et al. 2005, Ford 2005). The prevalence of metabolic syndrome has increased over the past few decades (Ford et al. 2004) and recent data indicate that 34% of adults in the United States are affected by metabolic syndrome (Ervin 2009). A better understanding of risk factors associated with metabolic syndrome would aid development of strategies to reduce its prevalence.

Mounting evidence suggests that the number of natural teeth is associated with several chronic diseases or conditions such as diabetes (Griffin et al. 2009, Kaur et al. 2009, Patel et al. 2013), obesity (Sheiham et al. 2002, Griffin et al. 2009, de Marchi et al. 2012, Ostberg et al. 2012), cardiovascular disease (Hung et al. 2004, Griffin et al. 2009), hypertension (Peres et al. 2012) or chronic inflammation (Holmlund et al. 2007, Janket et al. 2014). The observed associations may be explained, in part, by an alteration in dietary habits brought about by tooth loss, which impairs chewing ability; this may consequently influence dietary intake and diet quality, contributing to an increased risk of chronic diseases (Ritchie et al. 2002).

Systematic reviews have reported associations between periodontal

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disease and systemic diseases including metabolic syndrome (Linden et al. 2013) and provided evidence that periodontal therapy preserves natural teeth and improves biomarkers of cardiovascular disease and inflammation, such as serum levels of lipids and C-reactive protein (D'Aiuto et al. 2013). Despite these findings and evidence linking the number of natural teeth and individual conditions that comprise metabolic syndrome, associations between the number of natural teeth and metabolic syndrome itself have received little attention. A previous study examined tooth loss in 70-year-old adults and reported that subjects with metabolic syndrome had fewer teeth than those without metabolic syndrome (Holmlund et al. 2007). A recent study also suggested that a higher number of missing teeth was associated with the presence of metabolic syndrome in Finnish men aged between 45 and 74 years (Hyvärinen et al. 2014). Nonetheless, data from a nationally representative sample have not been reported. Further studies regarding tooth loss and metabolic syndrome are warranted to expand these previous findings for increased generalizability.

The objective of this study was to explore whether there is an association between the number of natural teeth and metabolic syndrome in adults using data from a nationally representative sample. In addition, relationships between the number of natural teeth and biometric and metabolic parameters were examined. It was hypothesized that having fewer natural teeth is associated with the presence of metabolic syndrome and unhealthier biometric and metabolic parameters in adults.

Material and Methods

Data source and study population

Data from the National Health and Nutrition Examination Survey (NHANES) were used in this study. The NHANES is a cross-sectional survey designed to assess the nutrition and health status of the non-institutionalized population in the United States, which includes physical examinations, health interviews, 24-h dietary recall, as well as collections of blood and urine samples at mobile examination centres (Centers for Disease Control and Prevention 2014). In 2005–2008, the NHANES oral health component involved an examination of participants 5 years or older. The examination was conducted by trained health technologists, who inquired about the oral health conditions of participants and performed a tooth count. The NHANES protocols were approved by National Center for Health Statistics Research Ethics Review Board and written informed consent was obtained from all participants. The methodology, survey instruments, data sets, quality control and assurance, are publicly available from the NHANES website (http://www.cdc.gov/nchs/nhanes.htm).

This study combined data from the NHANES 2005–2006 and the NHANES 2007–2008. Adults aged 20 years or older who completed the oral health examination with sufficient diagnostic information for metabolic syndrome were initially included ($n = 6423$). Among this population, 912 participants were excluded as they met one or more of the following criteria: had at least one tooth not assessed ($n = 12$), had missing information in covariates (described later) included in this study ($n = 669$), were pregnant or lactating women ($n = 252$) because of their different metabolic status associated with pregnancy or lactation compared to the general population. The final sample size was 5511.

Tooth count

The NHANES 2005–2008 oral health data included variables that recorded the status for each of the 32 teeth as one of the four categories: primary tooth present, permanent tooth present, tooth not present, or permanent dental root fragment present. In this study, the natural tooth was considered as present if the status was among the first two categories, and absent if the status was among the last two categories; the total number of natural teeth was then calculated after excluding third molars. Based on this information, participants were classified into one of the four groups: full dentition (28 teeth), 21–27 teeth, 1–20 teeth, or edentulous (no teeth). The number of 21 teeth was used as a cut-off value because having 21 or more teeth was considered as functional dentition (Ervin & Dye 2012).

Outcome variables

Diagnostic guidelines from the American Heart Association and National Heart, Lung, and Blood Institute (Grundy et al. 2005) were used to define metabolic syndrome. Participants who met at least three of the following five criteria: high waist circumference (≥102 cm in men, ≥88 cm in women), high triglycerides (≥1.7 mmol/l), low HDL cholesterol (<1.03 mmol/l in men, <1.3 mmol/l in women), high blood pressure (≥130 mmHg systolic blood pressure, ≥85 mmHg diastolic blood pressure, or current use of antihypertensive medications), and high fasting glucose (≥5.55 mmol/l or current use of hypoglycaemic medications) were defined as having metabolic syndrome. Those who did not meet at least three of the above criteria were classified as not having metabolic syndrome. The diagnostic guidelines also consider use of medications for high triglycerides or for low HDL cholesterol (Grundy et al. 2005). However, the NHANES did not specifically inquire about medications used for these two conditions; moreover, the prescribed medication data collected in the NHANES did not distinguish treatment purposes. As a result, the diagnostic criteria for high triglycerides and low HDL cholesterol to define metabolic syndrome were only based on biochemical data (Ervin 2009).

Biometric and metabolic parameters included in this study were body mass index (BMI); waist circumference; serum concentrations of C-reactive protein, total cholesterol, HDL cholesterol, LDL cholesterol, triglycerides; systolic blood pressure; diastolic blood pressure; and fasting plasma concentrations of glucose and insulin. Detailed methods for measurements of these outcomes can be found on the NAHNES website; a brief summary is available in a previous study (Zhu & Hollis 2013). In addition, homeostatic model assessment of insulin resistance (HOMA-IR) was calculated as an

index of insulin resistance (Matthews et al. 1985). Participants in the upper tertile of HOMA-IR were considered to have insulin resistance (Sumner & Cowie 2008).

Covariates

Demographical characteristics including age, gender, race/ethnicity (non-Hispanic white, non-Hispanic black, Hispanic, or other), ratio of family income to poverty (≥3.50, 1.86–3.49, or ≤1.85), as well as lifestyle factors including physical activity level (sedentary, moderately active, or vigorously active), smoking status (non-smoker, former smoker, or current smoker) and energy intake from the 24-h dietary recall collected at mobile examination centres, were included as covariates in the analysis (Zhu & Hollis 2013).

Statistical analysis

SAS version 9.3 (SAS Institute, Cary, NC, USA) was used for statistical analysis. Because of the multistage study design employed in the NHANES, 4-year sample weight and SAS survey procedures were used in this study. Characteristics of participants were compared by survey Chi-square tests. Biometric and metabolic parameters were analysed by survey linear regressions. Odds ratios (ORs) and 95% confidence intervals (CIs) for insulin resistance, metabolic syndrome as well as the five components of metabolic syndrome were obtained from survey logistic regression analyses, using the full dentition group as a reference group. Both unadjusted and covariates-adjusted outcomes were calculated.

Several stratified analyses for the association between the number of natural teeth and the presence of metabolic syndrome were conducted. First, the analyses were stratified by age (young adults, 20–44 years; middle-aged adults, 45–64 years; and older adults, 65 years or older). Second, the analyses were stratified by the presence of self-reported diabetes, and self-reported cardiovascular diseases. Self-reported diabetes was defined if the answer was "yes" to the question "have you ever been told by a doctor or health professional that you have diabetes or sugar diabetes?" in the diabetes questionnaire; self-reported cardiovascular diseases were defined if there was a reported diagnosis of angina, heart attack or coronary heart disease in the medical conditions questionnaire (Melzer et al. 2010).

Several sensitivity analyses were also conducted. First, the association in non-smokers was examined. Second, analyses using the number of natural teeth as a continuous variable were conducted. Additional analyses were conducted by defining metabolic syndrome based on diagnostic guidelines from the International Diabetes Federation (available at www.idf.org/metabolic-syndrome) rather than the American Heart Association and National Heart, Lung, and Blood Institute.

Data are expressed as weighted percentage or least square mean ± standard error where appropriate. $p < 0.05$ was considered statistically significant.

Results

Characteristics of participants

Excluding third molars, 1826 participants had full dentition, 2110 had 21–27 natural teeth, 1062 had 1–20 natural teeth and 513 were edentulous. Their weight percentage was 41.8 ± 1.5%, 38.5 ± 0.9%, 13.3 ± 0.9%, and 6.4 ± 0.6%, respectively. The gender and age distributions were significantly different among the four groups ($p = 0.021$ and $p < 0.001$, respectively, Table 1) with percentages of females and older adults being higher in the edentulous group. The percentages of non-Hispanic white, those with the ratio of family income to poverty less or equal to 1.85, sedentary participants, current smokers, as well as participants with metabolic syndrome, were also higher in the edentulous group ($p < 0.001$ for all, Table 1).

Associations between the number of natural teeth and metabolic syndrome

Table 2 shows the crude and adjusted ORs for the association between the number of natural teeth and the presence of each component of metabolic syndrome, as well as metabolic syndrome and insulin resistance. Crude ORs indicate an inverse association between the number of natural teeth and each of these conditions ($p < 0.05$ for all). The associations remained statistically significant after adjusting for the specified covariates ($p < 0.05$ for all conditions, except for high serum triglyceride concentration).

When stratified by age, significant associations between the number of natural teeth and the presence of metabolic syndrome were observed in young and middle-aged adults ($p < 0.001$ for both, Table 3), however, the association was not statistically significant in older adults ($p = 0.779$). The association was also significant in those without self-reported diabetes ($p = 0.025$) or cardiovascular diseases ($p = 0.010$), although statistically significant associations were not observed in participants with self-reported diabetes ($p = 0.264$) or cardiovascular diseases ($p = 0.144$) (Table 3). With these findings, additional analyses were conducted by further adjusting for self-reported diabetes and cardiovascular diseases in the analyses of data from all eligible participants. Compared to the previously obtained adjusted ORs for the association between the number of natural teeth and the presence of metabolic syndrome, slightly lower but still statistically significant adjusted ORs were obtained when self-reported diabetes and cardiovascular diseases were also included as covariates (data not shown).

Associations between the number of natural teeth and biometric and metabolic parameters

Table 4 presents the adjusted least square mean for each outcome by the number of natural teeth. Adjusting for covariates, the number of natural teeth was inversely associated with BMI ($p = 0.002$), waist circumference ($p = 0.001$), fasting plasma glucose concentration ($p = 0.003$), fasting plasma insulin concentration ($p = 0.006$), systolic blood pressure ($p < 0.001$), diastolic blood pressure ($p < 0.001$), and HOMA-IR ($p = 0.005$). In addition, the number of natural teeth was positively associated with serum HDL cholesterol concentration ($p = 0.003$). Nonetheless, there was no significant association

Table 1. Characteristics of US adults 20 years and older by the number of natural teeth (excluding third molars): NHANES 2005–2008 ($N = 5511$).

	28 teeth		21–27 teeth		1–20 teeth		Edentulous		Total	*P* value
	n	%*	*n*	%*	*n*	%*	*n*	%*		
Gender										
Male	996	44.1 ± 1.4	1077	36.9 ± 1.2	551	13.3 ± 1.1	248	5.7 ± 0.7	2872	0.021
Female	830	39.6 ± 1.9	1033	40.1 ± 1.4	511	13.2 ± 1.1	265	7.1 ± 0.7	2639	
Age (years)										
20–44	1294	61.9 ± 1.4	851	34.1 ± 1.2	97	3.1 ± 0.4	23	0.9 ± 0.3	2265	<0.001
45–64	424	30.1 ± 1.6	835	46.7 ± 1.5	470	17.4 ± 1.2	144	5.8 ± 0.7	1873	
≥65	108	10.9 ± 1.2	424	32.3 ± 2.2	495	33.0 ± 2.0	346	23.8 ± 1.8	1373	
Race/ethnicity										
Hispanic	470	41.8 ± 1.4	576	43.9 ± 1.4	236	11.7 ± 1.0	65	2.6 ± 0.4	1347	<0.001
Non-Hispanic White	967	42.8 ± 2.0	1019	37.2 ± 1.1	502	12.7 ± 1.2	333	7.3 ± 0.8	2821	
Non-Hispanic Black	300	32.7 ± 1.7	417	39.6 ± 2.1	297	21.6 ± 1.4	102	6.1 ± 0.6	1116	
Other	89	45.1 ± 3.4	98	42.0 ± 3.4	27	9.1 ± 2.0	13	3.8 ± 1.0	227	
Ratio of family income to poverty										
≤1.85	578	31.8 ± 2.1	785	36.4 ± 1.1	561	20.4 ± 1.6	317	11.4 ± 0.9	2241	<0.001
1.86–3.49	461	38.9 ± 2.0	561	38.5 ± 1.4	291	15.9 ± 1.3	124	6.7 ± 0.9	1437	
≥3.50	787	49.7 ± 1.7	764	39.8 ± 1.3	210	7.3 ± 0.7	72	3.2 ± 0.6	1833	
Physical activity										
Vigorously active	658	52.5 ± 1.8	596	37.0 ± 1.4	168	7.9 ± 0.9	55	2.6 ± 0.6	1477	<0.001
Moderately active	583	45.2 ± 2.3	621	38.6 ± 1.9	260	10.7 ± 1.2	119	5.5 ± 0.7	1586	
Sedentary	585	30.2 ± 1.6	893	39.6 ± 1.3	634	19.8 ± 1.1	339	10.4 ± 0.9	2451	
Smoking										
Non-smoker	1142	49.9 ± 1.4	1083	37.3 ± 1.4	433	9.3 ± 0.7	162	3.5 ± 0.4	2820	<0.001
Former smoker	359	35.0 ± 1.8	533	38.8 ± 1.6	345	16.8 ± 1.5	200	9.4 ± 0.9	1437	
Current smoker	325	31.5 ± 2.4	494	40.7 ± 1.7	284	18.0 ± 1.5	151	9.8 ± 1.2	1254	
Metabolic syndrome										
No	1357	49.9 ± 1.6	1235	37.4 ± 1.2	438	9.1 ± 0.8	174	3.6 ± 0.4	3204	<0.001
Yes	469	28.0 ± 1.3	875	40.3 ± 1.4	624	20.4 ± 1.1	339	11.3 ± 1.1	2307	

*Data were expressed as weighted row percentage ± standard error.

between the number of natural teeth and serum concentrations of C-reactive protein, total cholesterol, LDL cholesterol or triglycerides (all $p > 0.05$).

Sensitivity analyses

The sensitivity analyses generated similar findings to the main analyses. Namely, identified significant associations from the analyses of data from all eligible participants remained significant in the non-smoker subgroup; also, using a continuous variable of the number of natural teeth, or defining metabolic syndrome by the current diagnostic guidelines from the International Diabetes Federation, did not influence the results (data not shown).

Discussion

Results from this study suggest that the number of natural teeth is inversely associated with the presence of metabolic syndrome in adults. Compared to those with full dentition, participants with missing teeth were more likely to have metabolic syndrome when adjusted for confounding factors. Age-stratified analysis also revealed that the association was statistically significant in young and middle-aged participants, but not in older adults. In addition, tooth loss was significantly associated with BMI, waist circumference, blood pressure, serum concentration of HDL cholesterol, and fasting plasma concentrations of glucose and insulin; those without any missing teeth had a healthier outcome on these measurements.

Using data collected from 947 adults aged 70 years, Holmlund et al. (2007) compared the self-reported number of teeth (excluding third molars) in participants by the presence of metabolic syndrome. The average number of teeth was 21 in those without metabolic syndrome, which was significantly higher than an average of 18 teeth in those with metabolic syndrome (Holmlund et al. 2007). In contrast, the number of teeth was assessed by an independent assessor in our study. Moreover, our data were drawn from a larger population that included young and middle-aged adults, as well as older adults. In addition, the analytical approach in our study was different and involved analysis of covariate-adjusted outcomes.

A recent study also reported that the number of missing teeth was significantly associated with the presence of metabolic syndrome in middle-aged and older Finnish men when several confounding factors were adjusted for (Hyvärinen et al. 2014). This finding is supported by results from the analyses of data from all eligible participants in this study. However, age-stratified analysis in this study failed to observe significant associations in older adults. No data in the literature were available for direct comparisons to be made. It is possible that significant associations observed in the young age group may be confounded by other unmeasured factors. This is a limitation of this study and it warrants a comprehensive investigation by future studies.

Table 2. Associations between the number of natural teeth (excluding third molars) and each component of metabolic syndrome, metabolic syndrome, and insulin resistance: NHANES 2005–2008.

Condition*	Crude OR	95% CI	Adjusted† OR	95% CI
High waist circumference				
28 teeth	Reference		Reference	
21–27 teeth	1.90	[1.64, 2.20]	1.40	[1.20, 1.63]
1–20 teeth	3.14	[2.57, 3.85]	1.46	[1.13, 1.89]
Edentulous	4.53	[3.53, 5.81]	1.80	[1.27, 2.56]
High triglycerides				
28 teeth	Reference		Reference	
21–27 teeth	1.28	[1.02, 1.60]	1.18	[0.94, 1.47]
1–20 teeth	1.66	[1.34, 2.05]	1.23	[0.92, 1.63]
Edentulous	1.55	[1.17, 2.06]	1.08	[0.76, 1.55]
Low HDL cholesterol				
28 teeth	Reference		Reference	
21–27 teeth	1.40	[1.22, 1.59]	1.26	[1.06, 1.51]
1–20 teeth	1.78	[1.49, 2.13]	1.44	[1.19, 1.75]
Edentulous	2.10	[1.62, 2.73]	1.54	[1.13, 2.11]
High blood pressure				
28 teeth	Reference		Reference	
21–27 teeth	1.95	[1.69, 2.24]	1.08	[0.92, 1.26]
1–20 teeth	5.25	[4.25, 6.49]	1.26	[0.95, 1.66]
Edentulous	7.78	[6.52, 9.28]	1.45	[1.13, 1.87]
High fasting glucose				
28 teeth	Reference		Reference	
21–27 teeth	1.76	[1.41, 2.19]	1.30	[1.04, 1.62]
1–20 teeth	3.57	[2.88, 4.44]	1.50	[1.11, 2.03]
Edentulous	3.86	[2.51, 5.92]	1.42	[0.92, 2.19]
Metabolic syndrome				
28 teeth	Reference		Reference	
21–27 teeth	1.91	[1.63, 2.25]	1.32	[1.09, 1.59]
1–20 teeth	4.01	[3.43, 4.69]	1.55	[1.22, 1.98]
Edentulous	5.56	[4.23, 7.30]	1.79	[1.28, 2.51]
Insulin resistance				
28 teeth	Reference		Reference	
21–27 teeth	1.45	[1.14, 1.83]	1.39	[1.10, 1.74]
1–20 teeth	1.62	[1.31, 2.01]	1.37	[1.00, 1.87]
Edentulous	1.64	[1.20, 2.24]	1.40	[0.97, 2.02]

OR: odds ratio; CI: confidence interval.
*Definition of each condition: high waist circumference (≥102 cm in men, ≥88 cm in women); high triglycerides (≥1.7 mmol/l); low HDL cholesterol (<1.03 mmol/l in men, <1.3 mmol/l in women); high blood pressure (≥130 mmHg systolic blood pressure, ≥85 mmHg diastolic blood pressure, or current use of antihypertensive medications); high fasting glucose (≥5.55 mmol/l or current use of hypoglycaemic medications), metabolic syndrome (have at least three of the above five conditions), insulin resistance (homeostatic assessment model of insulin resistance in the upper tertile).
†Adjusted for age, gender, race/ethnicity, ratio of family income to poverty, physical activity, smoking status, and energy intake.

In agreement with previous studies (de Marchi et al. 2012, Ostberg et al. 2012, Hyvärinen et al. 2014), the number of natural teeth was inversely associated with waist circumference in this study; those with missing teeth were more likely to have central obesity. It has been reported that the hardness of habitual diet is inversely related to waist circumference (Murakami et al. 2007). Also, people with fewer pairs of posterior teeth had higher intake of saturated fat and cholesterol (Sahyoun et al. 2003). In addition, results from this study revealed a higher percentage of sedentary participants in those who had missing teeth. Taken together, these factors may contribute to the positive associations between tooth loss and obesity.

High fasting plasma glucose concentration is another component of metabolic syndrome. It was found that the number of missing teeth was higher among participants with a high blood glucose level (Hyvärinen et al. 2014). Several studies have demonstrated a positive association between tooth loss and diabetes (Griffin et al. 2009, Kaur et al. 2009, Patel et al. 2013). Nonetheless, a causal relationship has not been established yet and it may be bidirectional. On one hand, altered dietary pattern due to tooth loss results in higher intake of carbohydrate (Wakai et al. 2010) and lower intake of dietary fibre (Sahyoun et al. 2003); this dietary pattern increases the risk of diabetes (Schulze et al. 2004). On the other hand, uncontrolled high blood glucose in patients with diabetes may contribute to poor oral health conditions including tooth loss and periodontal disease, due to increased risk of oral inflammation and infection (Taylor et al. 2004).

This study also observed increased odds of having high blood pressure in edentulous participants. Similar findings have been observed in a population-based sample of Brazil adults (Peres et al. 2012). Another study of older adults in Korea also reported a negative association between the number of natural teeth and blood pressure (Lee et al. 2010). The change in dietary pattern may have partly contributed to increased blood pressure in edentulous people. In addition, a higher left ventricular mass is associated with tooth loss (Voelzke et al. 2007) and may also result in high blood pressure.

With regard to serum lipid profiles, this study found that the number of natural teeth was associated with serum concentration of HDL cholesterol, but not triglyceride, LDL cholesterol, or total cholesterol. A previous study in patients with type 2 diabetes reported similar results showing HDL cholesterol, rather than total cholesterol, was associated with tooth loss (Furukawa et al. 2007). Another study in older Finnish adults also found a positive relationship between the number of natural teeth and HDL cholesterol,

Table 3. Stratified analyses of associations between the number of natural teeth (excluding third molars) and metabolic syndrome: NHANES 2005–2008.

Stratification factor	21–27 teeth		1–20 teeth		Edentulous	
	OR	95% CI	OR	95% CI	OR	95% CI
Age (years)*						
20–44	1.51	[1.20, 1.90]	2.36	[1.50, 3.70]	3.86	[1.40, 10.65]
45–64	1.35	[0.99, 1.83]	2.51	[1.63, 3.87]	4.27	[2.40, 7.57]
≥65	1.11	[0.65, 1.88]	0.99	[0.62, 1.60]	1.13	[0.69, 1.85]
Diabetes†						
Yes	0.55	[0.23, 1.34]	0.70	[0.26, 1.84]	1.31	[0.50, 3.41]
No	1.32	[1.09, 1.59]	1.44	[1.09, 1.90]	1.47	[0.96, 2.26]
Cardiovascular diseases†						
Yes	2.74	[0.90, 8.28]	2.91	[1.10, 7.69]	2.13	[0.97, 4.68]
No	1.29	[1.08, 1.53]	1.46	[1.11, 1.91]	1.79	[1.23, 2.60]

OR: odds ratio; CI: confidence interval.
*Adjusted for gender, race/ethnicity, ratio of family income to poverty, physical activity, smoking status, and energy intake; the 28 teeth group was used as a reference group.
†Adjusted for age, gender, race/ethnicity, ratio of family income to poverty, physical activity, smoking status, and energy intake; the 28 teeth group was used as a reference group.

Table 4. Biometric and metabolic parameters by the number of natural teeth (excluding third molars): NHANES 2005–2008.

Measurement*,†	28 teeth	21–27 teeth	1–20 teeth	Edentulous
Body mass index (kg/m^2)	27.7 ± 0.3^{a}	28.7 ± 0.2^{b}	$28.6 \pm 0.4^{a,b}$	$28.6 \pm 0.3^{a,b}$
Waist circumference (cm)	95.2 ± 0.7^{a}	97.5 ± 0.5^{b}	98.2 ± 0.8^{b}	98.7 ± 0.9^{b}
C-reactive protein (mg/dl)	0.38 ± 0.03^{a}	0.39 ± 0.02^{a}	0.44 ± 0.04^{a}	0.49 ± 0.04^{a}
Total cholesterol (mmol/l)	5.14 ± 0.03^{a}	5.15 ± 0.03^{a}	5.06 ± 0.06^{a}	4.97 ± 0.07^{a}
HDL cholesterol (mmol/l)	1.44 ± 0.01^{a}	$1.40 \pm 0.01^{a,b}$	1.37 ± 0.01^{b}	1.34 ± 0.03^{b}
LDL cholesterol (mmol/l)	3.02 ± 0.05^{a}	3.03 ± 0.03^{a}	2.92 ± 0.06^{a}	2.88 ± 0.07^{a}
Triglycerides (mmol/l)	1.55 ± 0.05^{a}	1.61 ± 0.05^{a}	1.66 ± 0.08^{a}	1.66 ± 0.13^{a}
Systolic blood pressure (mmHg)	122.2 ± 0.6^{a}	$123.3 \pm 0.5^{a,b}$	$124.6 \pm 0.9^{a,b}$	126.0 ± 0.9^{b}
Diastolic blood pressure (mmHg)	68.8 ± 0.5^{a}	70.8 ± 0.5^{b}	$68.6 \pm 0.7^{a,b}$	$67.9 \pm 0.9^{a,b}$
Fasting glucose (mmol/l)	5.85 ± 0.07^{a}	$5.98 \pm 0.07^{a,b}$	6.23 ± 0.09^{b}	6.21 ± 0.09^{b}
Fasting insulin (pmol/l)	65.5 ± 2.8^{a}	73.7 ± 3.1^{b}	$73.3 \pm 4.1^{a,b}$	$70.4 \pm 4.2^{a,b}$
HOMA-IR‡	2.92 ± 0.16^{a}	3.38 ± 0.15^{b}	3.63 ± 0.26^{b}	$3.35 \pm 0.23^{a,b}$

*Data were expressed as the least square mean ± standard error, adjusted for age, gender, race/ethnicity, ratio of family income to poverty, physical activity, smoking status, and energy intake; groups with different alphabets ($^{a, b, c}$) in the same row were significantly different.
†Conversion factors: C-reactive protein, 1 mg/dl = 95.24 nmol/l; total cholesterol, HDL cholesterol and LDL cholesterol, 1 mmol/l = 38.67 mg/dl; triglyceride, 1 mmol/l = 88.57 mg/dl; glucose, 1 mmol/l = 18.02 mg/dl; insulin, 1 pmol/l = 0.14 μU/ml.
‡Homeostatic model assessment of insulin resistance.

with no such association for total cholesterol (Syrjala et al. 2010). In contrast, Hyvärinen et al. (2014) observed a higher number of missing teeth among participants with a high serum triglyceride concentration or a low serum HDL cholesterol concentration. While these studies are not directly comparable due to heterogeneous study populations, the observed favourable association between the number of natural teeth and serum cholesterol concentration may have partly explained the lower risk of cardiovascular diseases in people with more natural teeth (Hung et al. 2004, Griffin et al. 2009).

Previous studies have shown that tooth loss is associated with an increased serum level of C-reactive protein (Holmlund et al. 2007, Janket et al. 2014) and this may mediate the mortality of cardiovascular diseases (Janket et al. 2014). In both studies, bivariate correlations were used to determine the associations (Holmlund et al. 2007, Janket et al. 2014). This study found that the serum concentration of C-reactive protein was positively related to the number of natural teeth, nonetheless, such significant association disappeared when covariates were adjusted for. Additional studies are needed to confirm our findings.

There are other limitations in this study. First, the data in this study are from a cross-sectional survey and a causal relationship cannot be inferred. Consequently, it should be interpreted with caution. The observed association may be explained by changes in dietary pattern and diet quality due to missing teeth with impaired chewing ability (Marshall et al. 2002, Sahyoun et al. 2003), leading to an increased risk of metabolic syndrome (Millen et al. 2006). However, it is also possible that individuals who have metabolic syndrome lead an unhealthy life with a lack of knowledge, interests, or means to pursue a healthy lifestyle that preserves natural teeth and maintains a good oral health condition, or they may have an active immune or inflammatory response from periodontitis, leading to tooth loss. Future mechanistic studies are needed to elucidate biological mechanisms for the observed association between tooth loss and metabolic syndrome in this study. Second, the NHANES 2005–2008 oral health component did not involve assessment of denture use; additional studies may be needed to determine if the observed associations between the number of natural teeth and metabolic syndrome can be modified by use of denture. In addition, information such as when tooth

loss occurred, the cause of tooth loss, the periodontal health of remaining teeth, dental caries, and the number of occluding pairs was not available. Such information would be helpful to demonstrate any temporal relationship, or to characterize if and how mastication ability can modify the observed associations. Despite these limitations, this study, as the first study to our knowledge, evaluated associations between the number of natural teeth and the presence of metabolic syndrome in a nationally representative population. It used objectively assessed number of teeth and included a large number of participants; this reduced potential bias from self-reported dentition status and increased the generalizability of its conclusion.

In summary, this study suggested there was a significantly inverse association between the number of natural teeth and the presence of metabolic syndrome in adults in the United States; those with missing teeth had unhealthier biometric and metabolic parameters. Health practitioners should be aware of the possibility of coexisting conditions of tooth loss and metabolic syndrome, and if necessary, make referrals for examination and treatment.

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Clinical Relevance

Scientific rationale for the study: Studies have shown statistically significant associations between the number of natural teeth and individual conditions that comprise metabolic syndrome; however, associations between the number of natural teeth and metabolic syndrome itself have received little attention.

Principal findings: The number of natural teeth is inversely associated with the presence of metabolic syndrome in adults from a nationally representative sample.

Practical implications: The findings provide further evidence of a link between dentition status and systemic disease. The observed association between tooth loss and the presence of metabolic syndrome suggests medical practitioners may make appropriate referral for dental examinations of patients with metabolic syndrome. It also highlights the need for increased awareness of dental professionals who ought to explore presence of any metabolic syndrome conditions in persons with missing teeth, for potential referral for examinations and any needed treatment.