Clin Oral Invest (2012) 16:1647–1657
DOI 10.1007/s00784-011-0656-2

ORIGINAL ARTICLE

Risk indicators for the presence and extent of root caries among caries-active adults enrolled in the Xylitol for Adult Caries Trial (X-ACT)

André V. Ritter · John S. Preisser · Yunro Chung · James D. Bader · Daniel A. Shugars · Bennett T. Amaechi · Sonia K. Makhija · Kimberly A. Funkhouser · William M. Vollmer · X-ACT Collaborative Research Group

Received: 6 July 2011 / Accepted: 29 November 2011 / Published online: 24 December 2011

Abstract
Objective This paper uses baseline data from a randomized clinical trial to evaluate cross-sectional indicators of root caries in caries-active adults.
Materials and methods Adults (21–80 years) having at least 12 erupted teeth and between one and ten caries lesions were enrolled. Participants (n=437) received caries exams by trained, calibrated examiners and responded to baseline demographic and medical–dental questionnaires. We examined associations between baseline characteristics and (1) the presence of any root caries using Mantel–Haenszel hypothesis tests and odds ratio (OR) estimators and (2) the number of root surfaces with caries among study participants with exposed root surfaces (n=349) using Mantel–Haenszel mean score tests and Mann–Whitney estimators.
Results/conclusions Adjusting for study site and age, male gender [OR, 1.72; 95% confidence interval (CI), 1.08, 2.78], white race (OR, 2.39; 95% CI, 1.43, 3.98), recent dental visit (OR, 1.98; 95% CI, 1.07, 3.66), poor self-described oral health (OR, 2.65; 95% CI, 1.10, 6.39), and recent professional fluoride treatment (OR, 1.85; 95% CI, 1.06, 3.25) were significantly associated with increased odds to have any root caries, and study participants with exposed root surfaces characterized by male gender [Mann–Whitney probability estimate (MW)=0.57; 95% CI, 0.51, 0.63), white race (MW, 0.61; 0.55, 0.68), recent dental visit (MW, 0.58; 0.50, 0.67), poor self-described oral health (MW, 0.61; 0.53, 0.69), and flossing at least once per day (MW, 0.57; 95% CI, 0.51, 0.62) were significantly more likely to have a greater number of root surfaces with caries than a randomly selected study participant from their respective complementary subgroups (female gender, non-white, etc.).
Clinical relevance Our findings may help identify individuals at higher root caries risk.

Keywords Root caries · Risk indicators · Risk model

A. V. Ritter (✉) · J. D. Bader · D. A. Shugars
University of North Carolina at Chapel Hill School of Dentistry,
433 Brauer Hall, CB#7450,
Chapel Hill, NC 27599-7450, USA
e-mail: rittera@dentistry.unc.edu

J. S. Preisser · Y. Chung
University of North Carolina at Chapel Hill
Gillings School of Global Public Health,
Chapel Hill, NC, USA

B. T. Amaechi
University of Texas Health Sciences Center at San Antonio,
San Antonio, TX, USA

S. K. Makhija
University of Alabama School of Dentistry,
Birmingham, AL, USA

K. A. Funkhouser · W. M. Vollmer
The Kaiser Permanente Center for Health Research,
Portland, OR, USA

Introduction

Despite the progress achieved in the last 20 years in advancing oral health and reducing dental caries rates, root caries remains a prevalent infectious disease and an important clinical problem [1–4]. Recent reports based on independent, longitudinal studies estimate an annual root caries incidence of 26–27% among older adults [5, 6]. Root caries is more prevalent in older adults than in younger adults [5, 7–10]. By 2050, the number of adults aged 60 and older on the planet will more than triple to nearly two billion, at which time the population of older persons will be larger than the population of children for the first time in human history [11]. As adults are living and retaining their teeth longer, more root surfaces become physiologically or pathologically exposed and consequently at risk [2, 5, 12–15]. Therefore, root caries is likely to become an increasing clinical problem in the next several decades.

Dental caries is a multifactorial disease primarily caused by a complex interaction between cariogenic bacteria and fermentable carbohydrates on the tooth surface over time [16–18]. Many host factors, including dental biofilm (plaque) adherence and dynamics, saliva characteristics, immune system response, access to fluoride, and diet, play a role in the establishment and development of dental caries. It is believed that risk for caries is modulated by physical, biological, environmental, behavioral, and lifestyle-related factors [19–22]. The specific contribution of each of these factors in the makeup of an individual's or a population's root caries risk has not been adequately explored in multicenter studies of high-risk populations.

Knowing what risk indicators are significantly associated with root caries is important to design prevention programs in which available resources can be applied to those at elevated risk, maximizing the effectiveness of these programs. Recent studies show that ethnic origin, smoking, diabetes, gingival recession, age, and socioeconomic status are frequently associated with high caries prevalence [23–25]. Historically, analyses of cross-sectional studies of indicators of root caries have employed caries prevalence as the outcome measure [26–29]. Although this approach has yielded useful information, it may overlook predictors of disease severity or extent.

The aim of this paper is to identify associations between baseline characteristics and two different dependent measures: presence of any root caries and extent of root caries as given by the number of root surfaces with caries. Data from the Xylitol for Adult Caries Trial (X-ACT), a randomized clinical trial that includes data on dental caries, demographics, and oral and medical characteristics, were used. These data can provide insights into putative risk indicators for participants that may be at a higher risk for root caries.

Methods

Study design

X-ACT was a 3-year, randomized, double-blind, placebo-controlled, multi-center clinical trial that aimed to determine if daily use of xylitol mints reduced the coronal and root caries increment among caries-active adults [30]. After preliminary screening, enrollment, and run-in phases, a total of 691 adults were randomized at three clinical centers or study sites: The University of Alabama at Birmingham (UAB), The University of North Carolina at Chapel Hill (UNC), and The University of Texas Health Sciences Center at San Antonio (UTHSCSA). The Institutional Review Boards at the respective study sites reviewed and approved the study protocol, and all participants provided a written informed consent. Due to data irregularities that were uncovered at the UTHSCSA site, the study's Data Safety and Monitoring Board deemed that primary outcome analysis be limited to the UNC and UAB sites, although secondary analyses could use data from all three sites. The UTHSCSA caries examination data have not been called into question. The present analysis is therefore limited to only data from UNC and UAB (n=437).

Recruitment and inclusion and exclusion criteria

We recruited participants from our own dental school clinics, community dental clinics, and the general community [31]. To be eligible, participants had to be aged 21–80 years, have at least 12 teeth with exposed dental surfaces, and have one or more coronal or root caries lesions either at time of the baseline examination or documented within the past 12 months.

We excluded candidates if they had more than ten teeth with untreated caries lesions, a history of head and neck radiation, or were receiving long-term antibiotic therapy. We also excluded anyone with known allergy to xylitol or other mint components, serious illnesses, dietary restrictions, or those planning to leave the catchment area prior to the end of the study.

Oral examination

Trained and calibrated examiners (one primary examiner and a secondary examiner in each study site) performed a baseline oral exam of the teeth and supporting tissues for each participant in a standard dental operatory equipped with dental light and air–water syringe [32]. Examiners used a dental mirror and a Community Periodontal Index of Treatment Needs dental probe for the exams. Magnifying loupes were used at the discretion of the examiner. Radiographs were not used. With the help of a trained study recorder, examiners recorded coronal and root surfaces missing, sound, carious, restored, or sealed, as well as surfaces that were unable to be scored. Restored and sealed surfaces with caries were also recorded as such. Root surfaces were anatomically defined as those surfaces apical to the cementoenamel junction (CEJ).

The root caries classification system used was a modification of the International Caries Detection and Assessment System (ICDAS II) [33], summarized as follows:

- D1: non-cavitated lesion (clearly defined color change or loss of surface integrity less than 0.5 mm deep)

- D2: cavitated lesion (loss of surface integrity more than or equal to 0.5 mm deep)
- FD1: non-cavitated lesion (D1) adjacent to a restoration
- FD2: cavitated lesion (D2) adjacent to a restoration
- F: restored (filled) surface

From this information, we defined two root caries indicators: the presence of any root caries or restorations (D1, D2, FD1, FD2, or F) at baseline, and the number of root surfaces with caries or restorations. We similarly identified the presence of any coronal caries or restorations and a coronal caries index (CCI), defined as the number of coronal surfaces with caries or restorations divided by the total number of coronal surfaces at risk. Coronal caries was defined as any surface coronal to the CEJ with a restoration, a cavitated lesion, or a non-cavitated lesion, including lesions on previously restored surfaces.

Questionnaire data

Participants completed a series of baseline questionnaires that included information on demographics (including age, sex, race, and body mass index), medical history, and dental and oral health. Medical history items included history of high blood pressure; history of cancer chemotherapy or radiotherapy; history of diabetes; history of depression; and current use of antibiotics, tranquilizers, or antihistamines. Dental and oral health items included: time since last dental visit (less than 1 year, 1 year or more); time of most recent professional fluoride treatment (1 year or less, more than 1 year, never); daily use of over-the-counter (OTC) fluoride toothpaste (yes, no); daily use of OTC fluoride mouthwash (yes, no); frequency of tooth brushing in a typical day (once a day or less, more than once a day); frequency of dental flossing in a typical day (less than once a day, once a day or more); number of remaining teeth; self-described oral health (poor/very poor, fair, good, very good/excellent); and self-reported dry mouth symptoms (yes, no). Finally, we captured daily average consumption of mints/candy/gum (zero, one, two, three, or more exposures; these will be hereafter described simply as mints).

Statistical analyses

Associations of baseline characteristics with presence of any root caries among the study population and number of root surfaces with caries among those with exposed root surfaces were evaluated for statistical significance with Mantel–Haenszel hypothesis tests [34, 35], adjusting for study site. Additional tests of association of risk factors with the number of root surfaces with caries adjusting for study site and the number of exposed root surfaces used an extended Mantel–Haenszel procedure called nonparametric analysis of covariance [36, 37]. Row and column scores for these hypothesis tests were chosen according to the measurement scale (dichotomous, nominal, or ordinal) of the risk factors and response variable as reported in the tables.

The magnitude of the effects of risk factors with Mantel–Haenszel p values less than 0.10 was then quantified using Mantel–Haenszel odds ratio (OR) estimators for the strength of the association of risk factors with the presence of any root caries and Mann–Whitney rank measures of association estimators [38, 39] for the association of dichotomous (or dichotomized) risk factors with the number of root surfaces with caries. The Mann–Whitney estimator, which is a version of the Goodman–Kruskal rank correlation coefficient for ordinal variables when one of the two variables is dichotomous, gives the probability that a randomly selected study participant from one subgroup defined by a baseline dichotomous characteristic (e.g., female) had a greater number of root surfaces with caries than a randomly selected study participant from the complementary subgroup (e.g., male). Odds ratios and Mann–Whitney probabilities were stratified estimators, adjusting for study site and age (60 years or less vs. more than 60). An additional set of odds ratios additionally adjusted for the number of remaining teeth (26 or less vs. more than 26), and a further set of Mann–Whitney estimators simultaneously adjusted for study site and the number of remaining teeth; the Mann–Whitney methodology precluded adjustment for more than two risk factors at a time in these data. For estimation (but not for hypothesis tests), risk factors with three or more categories were dichotomized. We dichotomized all categorical risk indicators that passed an initial screening criterion of a Mantel–Haenszel $p<0.10$. Specifically, we combined black with other race for comparison with white/Caucasian, 0/1 mints vs. 2/3 mints, and the second and third categories of time of most recent professional fluoride treatment were combined to create an indicator variable for fluoride treatment in the past year. Finally, the first three categories of "self-described oral health" ("poor/very poor," "fair," and "good") were combined to create an indicator variable for very good/excellent oral health. SAS v. 9.2 was used for statistical analysis [40].

Results

The characteristics of the study participants by study site are summarized in Table 1. Four hundred thirty-seven caries-active adults participated in the study. The mean age for the entire sample was 48 (SD, 13; range, 21–80) years, while the mean number of remaining teeth was 25 (SD, 4; range, 11–32) teeth. The percentage of study subjects with any root caries was 46% and varied greatly between sites with higher prevalence noted at UNC (63%) than at UAB (26%). The mean number of exposed root surfaces was 12.2 (SD, 12.6; range, 0 to 64) and, among those with any exposed root

Table 1 Characteristics of the study participants across study sites (N=437)

		UAB (n=194)	UNC (n=243)
Variable		Mean (SD)	Mean (SD)
Age, years		47.1 (13.6)	49.1 (13.3)
BMI, kg/m^2		30.4 (7.7)	28.4 (6.5)
Number of remaining teeth		25.8 (4.0)	25.3 (3.7)
Number of root surfaces with caries (extent)		0.6 (1.5)	3.4 (5.0)
Number of exposed root surfaces		8.9 (11.4)	14.9 (12.8)
Coronal caries index		16.3 (10.5)	32.7 (15.8)
Variable		%	%
Root caries (prevalence)[a]	Yes	26	63
Coronal caries (prevalence)	Yes	99	100
Gender	Female	68	55
Race	White/Caucasian	38	77
	African-American	58	17
	Other race	4	7
Ethnic origin	Hispanic	4	3
Daily average mints/candy/gum consumption	0	38	28
	1	12	26
	2	13	20
	≥3	37	25
High blood pressure	Yes	35	30
Cancer chemo/radiotherapy	Yes	6	7
Diabetes	Yes	12	15
Depression	Yes	18	17
Medications[b]	Yes	8	14
Time since last dental visit	<1 year	58	93
Time of most recent professional fluoride treatment	≤1 year	29	74
	>1 year	40	23
	Never	31	4
Daily use of OTC fluoride toothpaste	Yes	92	90
Daily use of OTC fluoride mouthwash	Yes	42	35
Daily frequency of toothbrushing	≤Once/day	28	25
Daily frequency of flossing	<Once/day	52	43
Self-described oral health	Poor/very poor	21	14
	Fair	38	37
	Good	33	35
	Very good/excellent	8	14
Dry mouth symptoms	Yes	72	74

The item *daily average mints/candy/gum consumption* was not collected for all participants (n=327)

OTC over-the-counter

[a]The sample sizes for groups at risk for root caries (i.e., participants with exposed root surfaces) are 126 for UAB and 223 for UNC

[b]Use of antibiotics, tranquilizers, or antihistamines

surfaces (n=349), the mean number of root surfaces with caries was 2.70 (SD, 4.39; range, 0 to 29). Non-cavitated root carious surfaces (D1s and FD1s) contributed substantially to the root caries crude prevalence: 30.7% participants had D1 root lesions and 6.4% had FD1 root lesions, whereas 19.9% had D2 root lesions and 4.8% had FD2 root lesions. Approximately 26.5% participants had restored root surfaces with no current root caries.

Female/male ratio and race varied considerably across study sites, with the UAB site having larger percentages of females and African-Americans than the UNC site. Important differences were also noted in some dental and oral health variables, such as daily average mints/candy/gum consumption, timing of most recent dental visit, and timing of most recent professional fluoride application.

Bivariate associations for continuous and categorical variables with the presence of any root caries adjusting for study site as evaluated by Mantel–Haenszel tests are shown in Tables 2 and 3, respectively. In these analyses, increasing

Table 2 Means of continuous variables for participants with and without any surfaces with root caries and rank correlation of those variables with the number of surfaces with root caries, among those with exposed root surfaces, adjusted for study site

Variable	Mean (SD), participants with root caries (n=202)	Mean (SD), participants without root caries (n=235)	p value[a]	Correlation (SD) with number of surfaces with root caries (unadjusted)[b] (n=349)	Correlation (SD) with number of surfaces with root caries (adjusted)[c] (n=349)
Age, years	55.0 (10.8)	42.3 (12.8)	<0.001	0.33 (0.05)**	0.11 (0.05)
Number of remaining teeth	24.3 (3.8)	26.5 (3.5)	<0.001	−0.25 (0.05)**	−0.17 (0.05)*
BMI, kg/m^2	28.5 (6.1)	30.0 (7.9)	0.44	−0.14 (0.05)*	−0.06 (0.06)
Coronal caries index	33.0 (16.1)	18.8 (12.6)	<0.001	0.47 (0.04)**	0.48 (0.04)**

*p<0.01;**p<0.001

[a] Mantel–Haenszel correlation statistic with standardized midrank scores adjusting for study site;

[b] Spearman correlation coefficient

[c] Partial Spearman correlation coefficient adjusted for number of exposed root surfaces

age, decreasing number of remaining teeth, increasing CCI, male gender, white/Caucasian race, high blood pressure, more recent dental visit, more recent professional fluoride treatment, and dry mouth symptoms were significantly associated with having any root caries (p<0.05). In the analysis of Mantel–Haenszel odds ratio estimators for stratified 2×2 tables, male gender [OR, 1.72; 95% confidence interval (CI), 1.08, 2.78], white race (OR, 2.39; 95% CI, 1.43, 3.98), recent dental visit (OR, 1.98; 95% CI, 1.07, 3.66), poor self-described oral health (OR, 3.65; 95% CI, 1.51, 8.81), and recent professional fluoride treatment (OR, 1.85; 95% CI, 1.06, 3.25) were significantly associated with increased odds to have any root caries, adjusting for study site and age (Table 4). When odds ratio estimators additionally adjusted for the number of remaining teeth, recent professional fluoride treatment became nonsignificant, while the odds ratios for the other significant risk factors in Table 4 remained significant and changed little.

Bivariate associations for continuous and categorical variables with number of root surfaces with caries adjusting for study site among participants with any exposed root surfaces (n=349) as evaluated by Mantel–Haenszel tests are shown in Tables 2 and 5, respectively. In these analyses, increasing age, decreasing number of remaining teeth, decreasing BMI, increasing CCI, male gender, white/Caucasian race, high blood pressure, more recent dental visit, and daily flossing frequency were associated with the extent of root caries or the number of root surfaces with caries (p<0.05; second to last columns in Tables 2 and 5). Daily average mints/candy/gum and self-described oral health were nearly significant. After adjustment for the number of exposed root surfaces with nonparametric analysis of covariance, decreasing number of remaining teeth and increasing CCI were associated with the extent of root caries or the number of root surfaces with caries (last column in Table 2), while none of the factors in Table 5 remained significant (last column in Table 6).

In the analysis of Mann–Whitney estimators for stratified 2×r tables (where r is the number of distinct values taken by the response variable that is the number of root surfaces with caries; Table 6), several risk factors were significantly associated with the number of root surfaces with caries. Adjusting for study site and age, study participants with exposed root surfaces characterized by male gender [Mann–Whitney probability estimate (MW)=0.57; 95% CI, 0.51, 0.63], white race (MW, 0.61; 0.55, 0.68), recent dental visit (MW, 0.584; 0.501, 0.667), poor self-described oral health (MW, 0.61; 0.53, 0.69), and flossing at least once per day (MW, 0.57; 95% CI, 0.51, 0.62) had a significantly greater than 0.5 probability (i.e., 0.5 meaning there are no group differences) to have a greater number of root surfaces with caries than a randomly selected study participant from their respective complementary subgroups (female gender, non-white, etc.; Table 6). For example, a randomly selected study participant who visited a dentist in the last year is estimated to have a probability of 0.58 (95% CI, 0.50, 0.67) of having more root surfaces with caries than a randomly selected study participant who did not visit a dentist in the last year. When the Mann–Whitney estimators adjusted for study site and the number of remaining teeth, flossing at least once a day was no longer significant, while the odds ratios for the other significant risk factors in Table 6 remained significant and changed little.

Discussion

Root caries is an increasing clinical problem. The study of risk indicators associated with the presence of any root caries provides insights into root caries etiology. Moreover, the examination of caries extent as the number of root surfaces with caries has the potential to provide more discriminative information on root caries risk. The identification of variables significantly associated with root caries

Table 3 Association of categorical variables with any root caries, with *p* values adjusted for study site

Variable		*N*	Percent with root caries	p^b value
Gender	Female	265	38.5	0.001
	Male	172	58.1	
Race	White/Caucasian	260	58.5	<0.001
	African-American	153	26.1	
	Other	24	41.7	
Ethnic origin	Hispanic	15	40.0	0.647
	Not Hispanic	422	46.5	
Daily average mints/candy/gum consumption	0	108	46.3	0.260[c]
	1	62	51.6	
	2	55	45.5	
	≥3	102	39.2	
High blood pressure	Yes	139	54.7	0.002
	No	298	42.3	
Cancer chemo/radiotherapy	Yes	28	57.1	0.224
	No	409	45.5	
Diabetes	Yes	59	54.2	0.287
	No	378	45.0	
Depression	Yes	75	50.7	0.327
	No	362	45.3	
Medications[a]	Yes	50	60.0	0.174
	No	387	44.4	
Time since last dental visit	<1 year	336	53.0	0.016
	≥1 year	96	22.9	
Time of most recent professional fluoride treatment	≤1 year ago	195	58.5	0.015[c]
	>1 year ago	108	35.2	
	Never	56	26.8	
Daily use of OTC fluoride toothpaste	Yes	375	47.5	0.248
	No	39	41.0	
Daily use of OTC fluoride mouthwash	Yes	156	43.6	0.715
	No	255	47.8	
Daily frequency of toothbrushing	≤Once/day	115	40.0	0.139
	>Once/day	319	48.6	
Daily frequency of flossing	<Once/day	204	40.2	0.056
	≥Once/day	230	51.7	
Self-described oral health	Poor/very poor	74	39.2	0.186[c]
	Fair	163	50.9	
	Good	148	50.0	
	Very good/excellent	48	31.3	
Dry mouth symptoms	Yes	316	49.7	0.025
	No	117	37.6	

OTC over-the-counter

[a]Use of antibiotics, tranquilizers, and/or antihistamines

[b]Based on Mantel–Haenszel General Association Statistic (which is approximately equivalent to the Pearson chi-square statistic), unless otherwise noted

[c]Mantel–Haenszel Correlation Statistic with standardized midrank scores; the Mantel–Haenszel General Association *p* value for self-described oral health (as a nominal variable) was 0.01

presence and extent can also help identify which individuals or groups of individuals are best candidates for targeted prevention. X-ACT provides a unique opportunity to study root caries risk indicators, given that it enrolled only caries-active adults who had at least one recent coronal or root caries lesion within the last 12 months. In addition, being a multi-center trial, it can potentially result in findings that can be more generalizable than single-center clinical trials with a more homogeneous sample. However, the "target" population the X-ACT trial participants represent is elusive given the nonrandom enrollment of a high-risk caries population based on special selection criteria. Because most X-ACT participants had coronal caries (see coronal caries prevalence, Table 1), the results presented in this paper can inform identification of high root caries risk individuals only within a caries-active population.

This study used a nonparametric statistical analysis approach based on Mantel–Haenszel hypothesis tests that make minimal assumptions about the sampling process and distributional properties of the root caries data. Mantel–Haenszel tests are a common choice for the statistical analysis of data from clinical trials whose study populations, like the X-ACT

Table 4 Mantel–Haenszel odds ratio estimates (95% CI) for association of risk factors with any root caries adjusting for study site; study site and age; or study site and age (n=437)

Variable	Adjusted for *study site*, OR (95% CI)	Adjusted for *study site* and *age*, OR (95% CI)
Male	**2.00 (1.30, 3.03)**	**1.72 (1.08, 2.78)**
White/Caucasian	**2.34 (1.50, 3.65)**	**2.39 (1.43, 3.98)**
Daily mints ≥2	0.79 (0.49,1.26)	1.16 (0.68,1.97)
High blood pressure	**2.00 (1.28, 3.12)**	0.83 (0.49, 1.38)
Visited dentist in last year	**2.03 (1.14, 3.62)**	**1.98 (1.07, 3.66)**
Fluoride in last year[a]	**1.76 (1.08, 2.87)**	**1.85 (1.06, 3.25)**
Flossing ≥ once/day	1.49 (0.99, 2.25)	1.41 (0.89, 2.23)
Poor/fair/good oral health[b]	**3.17 (1.55, 6.49)**	**3.65 (1.51, 8.81)**
Dry mouth	**1.68 (1.06, 2.65)**	1.35 (0.80, 2.27)

Odds ratios statistically different than 1.0 at $p<0.05$ are in bold. For adjusted estimators, age categories were 60 years of less versus more than 60; number of remaining teeth was dichotomized with categories 26 teeth or less versus more than 26 teeth

[a] Whether most recent professional fluoride treatment was received in the last year

[b] Self-described oral health was dichotomized as very good or excellent versus poor/very poor, fair, or good

study population, are samples of convenience with subjects meeting very specific entrance criteria. In other words, the X-ACT study population was not obtained via random sampling (or even as an easily recognizable "representative" sample of some external population) so that random sampling-based methods such as logistic regression are not easily justified in our setting. Though their use is well justified, Mantel–Haenszel tests have the limitation that inference arising from their use has strict application only to the finite population of the X-ACT caries trial population, and extrapolation beyond requires non-sampling arguments. However, the ability to compute confidence intervals for odds ratios and rank association measures (Tables 4 and 6, respectively) depends upon stronger assumptions.

Although number of teeth has been found to be associated with root caries in previous studies [2, 41–44], the directionality of the association is not always the same. Having more teeth implies more surfaces at risk, but may also indicate good oral health and hence less root caries risk. Additionally, individuals with lower numbers of teeth may have lost teeth due to root caries. These factors make it difficult to clearly establish the relationship between number of teeth and root caries risk, and to make any firm recommendations for caries risk assessment and prescription of preventive strategies based on this variable alone. Therefore, our approach was to use number of remaining teeth as an adjustment factor rather than as a risk factor. We did not consider coronal caries index as either a risk factor or adjustment factor for root caries as it was strongly correlated with root caries and it would more properly be considered an outcome variable.

In this study, males were more likely than females to have any root caries adjusting for study site (Table 3), and males had a significantly greater number of root surfaces with caries than females adjusting for study site and number of root surfaces at risk (Table 5); similar results were obtained using stratified odds ratio and Mann–Whitney estimators adjusting for study site, age, and/or number of remaining teeth (Tables 4 and 6). The stratified analysis methods used in this paper preclude use of more than a few variables for covariate adjustment. Nonetheless, gender differences persisted after adjustment for race (not shown). The available literature is not conclusive on gender as a risk indicator [45–54]. Differences between males and females in terms of the other explanatory variables (demographics, medical, dental, education, socioeconomic, etc.) merit further study for confounding factors that may help explain gender risk differences as there seems to be no logical biological reason for these differences.

Race and ethnic background have been found to be risk indicators for root caries in previous studies [50, 51, 55–57]. While Ringelberg and colleagues [51] and Winn and colleagues [50] reported an increased risk for non-Hispanic blacks, one other longitudinal study reported that blacks were at lower risk compared to whites [56]. One study including Asians reported an increased caries risk for that race group [55]. In our study, white participants were more likely to have any root caries than those of other races when adjusting for study site and age category (Table 4). When also adjusting for number of remaining teeth, white race remained significant. Among participants with root surfaces at risk, whites were also more likely to have a greater number of root surfaces with caries when compared to those of other races, when adjusting for study site and age (Table 6), or study site and number of remaining teeth. As noted in Table 1, race was not evenly distributed throughout the study sites. African-Americans were mostly concentrated at UAB, while the majority of white/Caucasians were enrolled at UNC. These different distributions may influence the analyses, and future studies of risk prediction based on race (and ethnic origin) should attempt to more carefully balance these factors across multiple study sites.

Participants who had been to the dentist within the year prior to baseline had higher rates of any root caries (Table 3) and a greater number of root surfaces with caries (Table 5) than participants who had not been to the dentist within the last year. Additionally, participants who had been to the dentist within the year had a greater number of exposed root surfaces, but the number of root surfaces with caries was not significantly associated with time since last dental visit adjusting for the number of

Table 5 Association of individual characteristics with number of root surfaces with caries (RSC) among those with exposed root surfaces (n=349), with p values adjusted for study site

Variable		*N*	Mean RSC	p^b value	p^d value
Gender	Female	197	2.02	0.004	0.281
	Male	152	3.58		
Race	White/Caucasian	225	3.47	0.002	0.143
	African-American	103	1.04		
	Other	21	2.57		
Ethnic origin	Hispanic	13	1.23	0.263	0.077
	Not Hispanic	336	2.75		
Daily average mints/candy/gum consumption	0	87	2.56	0.073[c]	0.585[c]
	1	50	2.94		
	2	41	4.17		
	≥3	81	1.78		
High blood pressure	Yes	121	3.04	0.026	0.454
	No	228	2.51		
Cancer chemo/radiotherapy	Yes	25	3.24	0.233	0.218
	No	324	2.65		
Diabetes	Yes	53	2.25	0.854	0.944
	No	296	2.78		
Depression	Yes	64	2.97	0.294	0.940
	No	285	2.64		
Medications[a]	Yes	42	3.14	0.678	0.263
	No	307	2.64		
Time since last dental visit	<1 year	277	3.09	0.016	0.800
	≥ 1 year	68	1.21		
Time of most recent professional fluoride treatment	≤1 year ago	171	3.47	0.217[c]	0.415[c]
	>1 year ago	76	1.95		
	Never	41	1.29		
Daily use of OTC fluoride toothpaste	Yes	301	2.75	0.599	0.300
	No	32	2.75		
Daily use of OTC fluoride mouthwash	Yes	124	2.75	0.959	0.220
	No	208	2.63		
Daily frequency of toothbrushing	≤Once/day	83	2.42	0.416	0.993
	>Once/day	264	2.8		
Daily frequency of flossing	<Once/day	156	2.11	0.024	0.550
	≥Once/day	191	3.19		
Self-described oral health	Poor/very poor	59	3.71	0.080[c]	0.128[c]
	Fair	131	2.87		
	Good	122	2.45		
	Very good/excellent	35	1.29		
Dry mouth symptoms	Yes	261	2.77	0.366	0.063
	No	86	2.51		

OTC over-the-counter

[a] Use of antibiotics, tranquilizers, and/or antihistamines

[b] Based on Mantel–Haenszel Mean Score Statistic with standardized midrank scores adjusting for study site unless otherwise noted

[c] Mantel–Haenszel Correlation Statistic with standardized midrank scores adjusting for study site

[d] Mantel–Haenszel test adjusting for study site and for number of root surfaces with caries at risk via nonparametric analysis of covariance

exposed root surfaces. Although this may be an artifact of the effect of the UNC site having a large proportion of the participants with root caries and under active dental care, one other study also reported that participants who visited the dentist in the previous year were more likely to have root caries than those who did not [23]. This hardly indicates that going to the dentist is a risk factor for root caries, but may indicate that individuals (at least those in our study) still visit the dentist more for curative rather than for preventive reasons.

Table 6 Mann–Whitney (MW) estimators of the probability that a randomly selected participant from the subgroup listed will have a greater number of root surfaces with caries than a randomly selected person for the complementary group not listed (n=349)

Variable	Adjusted for *study site*, MW (95% CI)	Adjusted for *study site* and *age*, MW (95% CI)
Male	**0.58 (0.53, 0.64)**	**0.57 (0.51, 0.63)**
White/Caucasian	**0.61 (0.55, 0.68)**	**0.61 (0.55, 0.68)**
Daily mints ≥2	0.46 (0.39, 0.52)	0.49 (0.42, 0.56)
High blood pressure	**0.57 (0.51, 0.63)**	0.53 (0.46, 0.59)
Visited dentist in last year	**0.60 (0.52, 0.67)**	**0.58 (0.50, 0.67)**[c]
Fluoride in last year[a]	0.53 (0.46, 0.61)	0.54 (0.47, 0.61)
Flossing ≥once/day	**0.57 (0.51, 0.62)**	**0.57 (0.51, 0.62)**
Poor/fair/good oral health[b]	**0.66 (0.59, 0.74)**	**0.61 (0.53, 0.69)**
Dry mouth	0.53 (0.46, 0.60)	0.53 (0.46, 0.59)

Mann–Whitney probabilities statistically different than 0.5 at $p<0.05$ are in bold. For adjusted estimators, age was dichotomized with categories 60 years of less versus more than 60; number of remaining teeth was dichotomized with categories 26 teeth or less versus more than 26 teeth

[a] Whether most recent professional fluoride treatment was received in the last year; for this variable, the estimate that adjusted for age did not adjust for site due to sparse data

[b] Self-described oral health was dichotomized as very good or excellent versus poor/very poor, fair, or good

[c] The estimate 0.584 is considered statistically significant because its confidence interval (0.501, 0.667) excludes 0.500

This study is limited by the cross-sectional nature of the data, which precludes establishing definitive causal relationships between the exposure and outcome variables. Moreover, the study eligibility criteria and the nonrandom manner in which participants were recruited both limit the generalizability of our results. Another limitation is the moderately narrow scope of the information on putative risk indicators available in the database. For example, no information was available on plaque index and composition, saliva characteristics (pH, buffer capacity, flow rate, and microbiological content), smoking, and dietary habits, all of which are known to be associated with root caries [58].

Additionally, the substantial demographic differences between study sites can be both a strength and a weakness of the study. Although these differences provide insights into putative root caries risk indicators in diverse populations, the heterogeneous nature of the combined data can limit the interpretation of the analyses. This limitation should be considered when comparing our results to those of other studies, especially those based on random population samples, as ours is a highly selected sample. Additionally, we cannot rule out confounding effects that we did not measure (e.g., diet and fluoridated water). The study participants are being followed annually, and future studies will explore whether the observed baseline risk indicators will maintain their relevance or if other indicators are revealed.

Although it is an accepted epidemiological approach, the inclusion of non-carious restored (F) surfaces as caries events likely overestimates root caries prevalence. One study found that as much as 65% of the root caries increment can be due to restored surfaces [59]. Counting restorations as caries does not accurately reflect the carious state of that surface at the time of the examination. Furthermore, not all root restorations are placed due to caries. It has been reported that as many as 55% of the restorations on buccal root surfaces are due to non-carious defects [60]. However, most caries indices, including DMFS and extent (number of root surfaces with caries), count restorations (F surfaces) as caries events, and this was the method we elected to use so that our results could be more easily contrasted with previous findings employing a similar methodology. The ICDAS caries classification system may afford the opportunity to avoid the problematic inclusion of the F and M components as “markers” of caries [61]. In our study, if F surfaces were not included as caries events in the prevalence and extent calculations, we would obtain a prevalence of 37% and mean number of root surfaces with caries of 1.7. This represents a 20% decrease in prevalence and a 38% decrease in mean number of root surfaces with caries from what we reported.

In conclusion, the analyses of the baseline data available from X-ACT study participants in two clinical centers indicated that, adjusting for study site and age, male gender, white race, recent dental visit, and poor self-described oral health were significantly associated with increased odds to have any root caries and with greater chance to have an increased number of root surfaces with caries. In contrast, participants with recent professional fluoride treatment had greater odds of any caries, while participants who reported flossing at least once a day had greater chance to have an increased number of root surfaces with caries. These baseline associations will be explored further in longitudinal analyses of these participants and risk indicators. Future studies of root caries risk should develop and validate risk models in large longitudinal studies of high-risk participants.

Acknowledgments The authors would like to thank all X-ACT clinical and managerial staff that contributed to this study. The Kaiser Permanente Center for Health Research (Portland, OR) is the data coordinating center (DCC). Note that only baseline data are reported here, and that due to scope of effort constraints, the analyses presented in this paper were not conducted at or verified by the DCC. This study was supported by NIDCR grants U01DE018038, U01DE018047, U01DE018048, U01DE018049, U01DE018050, and T32DE017245.

Conflict of interest The authors declare that they have no conflict of interest.

References

1. Donovan T (2008) Critical appraisal: protocol for the prevention and management of root caries. J Esthet Restor Dent 20:405–411
2. Fure S (2004) Ten-year cross-sectional and incidence study of coronal and root caries and some related factors in elderly Swedish individuals. Gerodontology 21:130–140
3. Nalcaci R, Erdemir EO, Baran I (2007) Evaluation of the oral health status of the people aged 65 years and over living in near rural district of Middle Anatolia, Turkey. Arch Gerontol Geriatr 45:55–64
4. Vilstrup L, Holm-Pedersen P, Mortensen EL, Avlund K (2007) Dental status and dental caries in 85-year-old Danes. Gerodontology 24:3–13
5. Griffin SO, Griffin PM, Swann JL, Zlobin N (2004) Estimating rates of new root caries in older adults. J Dent Res 83:634–638
6. Ritter AV, Shugars DA, Bader JD (2010) Root caries risk indicators: a systematic review of risk models. Community Dent Oral Epidemiol 38:383–397
7. Clarkson JE (1995) Epidemiology of root caries. Am J Dent 8:329–334
8. Shay K (1997) Root caries in the older patient: significance, prevention, and treatment. Dent Clin North Am 41:763–793
9. Curzon ME, Preston AJ (2004) Risk groups: nursing bottle caries/caries in the elderly. Caries Res 38(Suppl 1):24–33
10. Thomson WM (2004) Dental caries experience in older people over time: what can the large cohort studies tell us? Br Dent J 196:89–92, Discussion 87
11. Watkins K (2009) United Nations Human Development Report. http://hdr.undp.org/en/media/hdr05_complete.pdf. Accessed 12 Nov 2009
12. Hamasha AA, Warren JJ, Hand JS, Levy SM (2005) Coronal and root caries in the older Iowans: 9- to 11-year incidence. Spec Care Dentist 25:106–110
13. Saunders RH Jr, Meyerowitz C (2005) Dental caries in older adults. Dent Clin North Am 49:293–308
14. Chalmers JM, Carter KD, Spencer AJ (2005) Caries incidence and increments in Adelaide nursing home residents. Spec Care Dentist 25:96–105
15. Drake CW, Beck JD, Lawrence HP, Koch GG (1997) Three-year coronal caries incidence and risk factors in North Carolina elderly. Caries Res 31:1–7
16. Anderson M (2002) Risk assessment and epidemiology of dental caries: review of the literature. Pediatr Dent 24:377–385
17. Simmonds RS, Tompkins GR, George RJ (2000) Dental caries and the microbial ecology of dental plaque: a review of recent advances. N Z Dent J 96:44–49
18. Ettinger RL (1999) Epidemiology of dental caries. A broad review. Dent Clin North Am 43:679–694, vii
19. Featherstone JD (1999) Prevention and reversal of dental caries: role of low level fluoride. Community Dent Oral Epidemiol 27:31–40
20. Fejerskov O (2004) Changing paradigms in concepts on dental caries: consequences for oral health care. Caries Res 38:182–191
21. Selwitz RH, Ismail AI, Pitts NB (2007) Dental caries. Lancet 369:51–59
22. Touger-Decker R, van Loveren C (2003) Sugars and dental caries. Am J Clin Nutr 78:881S–892S
23. Du M, Jiang H, Tai B, Zhou Y, Wu B, Bian Z (2009) Root caries patterns and risk factors of middle-aged and elderly people in China. Community Dent Oral Epidemiol 37:260–266
24. Hintao J, Teanpaisan R, Chongsuvivatwong V, Dahlen G, Rattarasarn C (2007) Root surface and coronal caries in adults with type 2 diabetes mellitus. Community Dent Oral Epidemiol 35:302–309
25. Wu W-H, Peng W, Zhang TH (2006) Analyzing the risk factors of root caries by logistic regression analysis. Journal of Xi'an Jiaotong University (Medical Sciences) 27:298–299
26. Reiker J, van der Velden U, Barendregt DS, Loos BG (1999) A cross-sectional study into the prevalence of root caries in periodontal maintenance patients. J Clin Periodontol 26:26–32
27. Whelton HP, Holland TJ, O'Mullane DM (1993) The prevalence of root surface caries amongst Irish adults. Gerodontology 10:72–75
28. McDermott RE, Hoover JN, Komiyama K (1991) Root surface caries prevalence and associated factors among adult patients in an acute care hospital. J Can Dent Assoc 57:505–508
29. Katz RV, Hazen SP, Chilton NW, Mumma RD Jr (1982) Prevalence and intraoral distribution of root caries in an adult population. Caries Res 16:265–271
30. Bader JD, Shugars DA, Vollmer WM, Gullion CM, Gilbert GH, Amaechi BT, Brown JP (2010) Design of the xylitol for adult caries trial (X-ACT). BMC Oral Health 10:22
31. Bader JD, Robinson DS, Gilbert GH, Ritter AV, Makhija SK, Funkhouser KA, Amaechi BT, Shugars DA, Laws R (2010) Four "lessons learned" while implementing a multi-site caries prevention trial. J Public Health Dent 70:171–175
32. Banting DW, Amaechi BT, Bader JD, Blanchard P, Gilbert GH, Gullion CM, Holland JC, Makhija SK, Papas A, Ritter AV, Singh ML, Vollmer WM (2011) Examiner training and reliability in two randomized clinical trials of adult dental caries. J Public Health Dent 71(4):335–344
33. Ismail AI, Sohn W, Tellez M, Amaya A, Sen A, Hasson H, Pitts NB (2007) The International Caries Detection and Assessment System (ICDAS): an integrated system for measuring dental caries. Community Dent Oral Epidemiol 35:170–178
34. Landis JR, Sharp TJ, Kuritz SJ, Koch GG (1998) Mantel–Haenszel methods. In: Armitage P, Colton T (eds) Encyclopedia of biostatistics. Wiley, New York
35. Mantel N, Haenszel W (1959) Statistical aspects of the analysis of data from retrospective studies of disease. J Natl Cancer Inst 22:719–748
36. Koch GG, Amara IA, Davis GW, Gillings DB (1982) A review of some statistical methods for covariance analysis of categorical data. Biometrics 38:563–595
37. Preisser JS, Koch GG (1997) Categorical data analysis in public health. Annu Rev Public Health 18:51–82
38. Koch GG, Tangen CM, Jung JW, Amara IA (1998) Issues for covariance analysis of dichotomous and ordered categorical data from randomized clinical trials and non-parametric strategies for addressing them. Stat Med 17:1863–1892
39. Mann HB, Whitney DR (1947) On a test of whether one of two random variables is stochastically larger than the other. Ann Math Stat 18:50–60
40. Stokes ME, Davis CS, Koch GG (2000) Categorical data analysis using the SAS system, 2nd edn. SAS Institute Inc., Cary
41. Gilbert GH, Duncan RP, Dolan TA, Foerster U (2001) Twenty-four month incidence of root caries among a diverse group of adults. Caries Res 35:366–375
42. Joshi A, Papas AS, Giunta J (1993) Root caries incidence and associated risk factors in middle-aged and older adults. Gerodontology 10:83–89
43. Phelan JA, Mulligan R, Nelson E, Brunelle J, Alves ME, Navazesh M, Greenspan D (2004) Dental caries in HIV-seropositive women. J Dent Res 83:869–873
44. Ravald N, Birkhed D (1992) Prediction of root caries in periodontally treated patients maintained with different fluoride programmes. Caries Res 26:450–458
45. Loesche WJ, Taylor GW, Dominguez LD, Grossman NS, Stoll J (1999) Factors which are associated with dental decay in the older individual. Gerodontology 16:37–46
46. Nicolau B, Srisilapanan P, Marcenes W (2000) Number of teeth and risk of root caries. Gerodontology 17:91–96
47. Imazato S, Ikebe K, Nokubi T, Ebisu S, Walls AW (2006) Prevalence of root caries in a selected population of older adults in Japan. J Oral Rehabil 33:137–143

48. Avlund K, Holm-Pedersen P, Morse DE, Viitanen M, Winblad B (2003) Social relations as determinants of oral health among persons over the age of 80 years. Community Dent Oral Epidemiol 31:454–462
49. Hawkins RJ (1999) Functional status and untreated dental caries among nursing home residents aged 65 and over. Spec Care Dentist 19:158–163
50. Winn DM, Brunelle JA, Selwitz RH, Kaste LM, Oldakowski RJ, Kingman A, Brown LJ (1996) Coronal and root caries in the dentition of adults in the United States, 1988–1991. J Dent Res 75 Spec No: 642–651
51. Ringelberg ML, Gilbert GH, Antonson DE, Dolan TA, Legler DW, Foerster U, Heft MW (1996) Root caries and root defects in urban and rural adults: the Florida Dental Care Study. J Am Dent Assoc 127:885–891
52. Lin HC, Wong MC, Zhang HG, Lo EC, Schwarz E (2001) Coronal and root caries in Southern Chinese adults. J Dent Res 80:1475–1479
53. Luan WM, Baelum V, Chen X, Fejerskov O (1989) Dental caries in adult and elderly Chinese. J Dent Res 68:1771–1776
54. Petersen PE, Kaka M (1999) Oral health status of children and adults in the Republic of Niger, Africa. Int Dent J 49:159–164
55. Powell LV, Leroux BG, Persson RE, Kiyak HA (1998) Factors associated with caries incidence in an elderly population. Community Dent Oral Epidemiol 26:170–176
56. Lawrence HP, Hunt RJ, Beck JD (1995) Three-year root caries incidence and risk modeling in older adults in North Carolina. J Public Health Dent 55:69–78
57. Graves RC, Beck JD, Disney JA, Drake CW (1992) Root caries prevalence in black and white North Carolina adults over age 65. J Public Health Dent 52:94–101
58. Ritter AV, Shugars DA, Bader JD (2009) Root caries risk indicators: a systematic review of risk models (unpublished)
59. Leske GS, Ripa LW (1989) Three-year root caries increments: an analysis of teeth and surfaces at risk. Gerodontology 8:17–21
60. Walls AW, Silver PT, Steele JG (2000) Impact of treatment provision on the epidemiological recording of root caries. Eur J Oral Sci 108:3–8
61. International Caries Detection and Assessment System (ICDAS) Coordinating Committee. Rationale and evidence for the International Caries Detection and Assessment (ICDAS II). (2005) Paper presented at the 2005 Indiana Caries Conference, Indiana, July 1, 2005