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ABSTRACT

The current evidence on the role of the social, behavioral, and community determinants of dental caries is based on cross-sectional analyses. The available evidence has not been based on analysis of multiple determinants within the same population. This longitudinal study addresses both of these limitations. The study included data from 788 dyads of children and their caregivers (77% follow-up), who were examined in 2002-03 and 2004-05. The families were assessed by calibrated dentists for severity of caries at both time periods. Additionally, the caregivers answered questionnaires administered by trained interviewers. The caries increment was adjusted for reversals. Significant predictors of higher caries increment were higher consumption of soda drinks, older age of child, greater weight-for-age, fewer dental treatment visits, higher baseline caries levels of children and their caregivers, dental fatalism, and neighborhood disadvantage status. The selected risk factors in the final model explained about 20% of the variation in the increment.

KEY WORDS: dental caries, cohort, social, behavioral, epidemiology

Predictors of Dental Caries Progression in Primary Teeth

INTRODUCTION

There is emerging evidence that social and behavioral factors play a significant role in developing dental caries in the primary dentition (Hallett and O'Rourke, 2003; Vachirarojpisan *et al.*, 2004; Willems *et al.*, 2005). Dental caries, especially in young children, should be prevented with the use of chronic disease management models that incorporate multiple strategies to target risk factors at the individual, family, clinical, and community levels (Brown *et al.*, 2006). A recent model, proposed by Fisher-Owens *et al.* (2007), depicts a complex interplay among social and physical environments, health behaviors, and dental and medical care. Guided by the Fisher-Owens *et al.* model, this paper describes the findings of a secondary analysis of data on the progression of caries that were collected from low-income African-American children aged 0-5 yrs and their caregivers in 2002-03 (Wave 1 [W1]) and 2004-05 (Wave 2 [W2]). The aim of the longitudinal analysis was to identify which factors at the individual, family, and community levels were associated with the development of new decayed, missing, and filled tooth surfaces.

METHODS

Sample

A cohort of low-income African-American children and their caregivers was selected by a two-stage area probability selection method and followed for 2 yrs. In total, 1386 families with at least one African-American child aged 0-5 yrs in selected neighborhoods were identified. Of those families, 1021 dyads of a child and a caregiver completed data collection in W1. The combined screening and interviewing response rate in W1 was 74%. Details of the sampling design and data collection procedures have been described in previous reports (Sohn *et al.*, 2007; Ismail *et al.*, 2008). Participants were followed in W2, when 77% (n = 790) returned to complete an interview and clinical examination. Two children were excluded because the dental examination could not be carried out, leaving a final sample of 788 (Table 1). This study was approved by the University of Michigan Health Sciences IRB. The caregivers consented to the examination of the family, provided information about themselves and their children, and consented for access to the child's Medicaid record. Of the 788 children included in this analysis, 698 had a dental record with Medicaid. The 90 children with no dental record were included in the "no dental visit" group.

Outcome Measures: Dental Caries

Four dentists with good-to-excellent reliability (Appendix Tables 1-4 describe the reliability statistics) assessed the caries status of all primary tooth surfaces using the International Caries Detection and Assessment System (ICDAS) (Ismail *et al.*, 2007) (Appendix Table 5 describes the ICDAS coding system). The numbers of non-cavitated lesions (d₁₋₂: ICDAS codes 1—2), cavitated/dentinal lesions (d₃₋₆: ICDAS codes 3—6), filled lesions (f), and missing lesions due to caries (m) were counted for each sampled child. The following 6 indices were computed to evaluate caries severity in the primary dentition: d₁₋₂, d₃₋₆, filled surfaces, missing surfaces, d₃₋₆mfs, and d₁₋₆mfs (Ismail *et al.*, 2007). The caries status of each tooth surface in W2 was compared with the W1

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Table 1. Demographic Characteristics of Caregivers and Children (n = 788)

	N (weighted %)
Caregivers	
Age: Weighted mean (SE)	29.1 (0.3)
Gender	
Male	36 (3.6)
Female	752 (96.4)
Education	
Less than high school	361 (46.0)
High school degree or higher	427 (54.0)
Annual household income	
< \$10K	353 (44.9)
≥ \$10K	435 (55.1)
Full-time employment	
Yes	250 (32.4)
No	538 (67.6)
Children	
Age: Weighted mean (S.E.)	2.6 (0.1)
Gender	
Male	372 (50.6)
Female	416 (49.4)
Weight-for-age percentile	
1: 0-26.9%	198 (25.7)
2: 27-56.4%	196 (24.5)
3: 56.7-84.2%	197 (23.6)
4: 84.3-100%	197 (26.1)

status, and increments were assessed for each child (Table 2). However, there was a small number of surfaces with reversals (0.3% of total 78,800 surfaces), which could have occurred due to examiners' errors as well as transitions from non-cavitated caries lesions to sound tooth surfaces. To account for these reversals, Beck *et al.* (1995) proposed an adjustment formula based on the assumption that there is a positive relationship between the frequency of a false-negative diagnosis and baseline caries, and a negative relationship between the frequency of a false-positive diagnosis and baseline caries. These two assumptions were met in the data used in this analysis. Using the adjustment formula, we calculated adjusted increments for d_{3-6} mfs and d_{1-6} mfs.

Determinants of Children's Oral Health

Guided by the Fisher-Owens *et al.* (2007) conceptual model, we compiled a list of the factors included in the model and for which data are available (Table 3). In this analysis, we tested associations between these risk factors in W1 and the increments of caries between W1 and W2.

Child-level Factors

Included factors were age, gender, and having ever been diagnosed with asthma. Additional information included a grouping variable of baseline d_{1-6} mfs scores (1 = none, 2 < 7, 3 ≥ 7), and weight-for-age percentiles (grouped by the quartiles) computed according to the 2000 Centers for Disease Control and Prevention growth charts (Kuczmarski *et al.*, 2000) in lieu of a BMI measure for young children. Risk factors associated with children's social environment included current participation in WIC or Head Start programs. Consumption of soda drinks (carbonated sugared drinks) was measured as the number of days children had consumed sodas during the preceding week (1 = none, 2 = 1 day, 3 = 2-6 days, 4 = every day), according to the Block Kids Food Frequency Questionnaire® (Berkeley, CA, USA) and administered to the caregivers by trained interviewers. We created categorical

Table 2. Transition of Caries Status between 2002-03 (Wave 1) and 2004-05 (Wave 2)

Caries Indices	W1	W2
New d_{1-6} mfs	Sound	d_{1-2} *
	Sound	d_{3-6}
	Sound	f_0
	Sound	f_{1-2}
	Sound	f_{3-6}
	d_{1-2}	d_{3-6}
New d_{3-6} mfs	f_0	f_{1-2}
	f_0	f_{3-6}
	f_{1-2}	f_{3-6}
	Sound, d_{1-2} , d_{3-6} , f_0	M
	Sound	d_{3-6}
	Sound	f_0
New d_{1-2}	Sound	f_{1-2}
	Sound	f_{3-6}
	d_{1-2}	d_{3-6}
	f_0	f_{3-6}
	f_{1-2}	f_{3-6}
	Sound, d_{1-2} , d_{3-6} , f_0	M
New d_{3-6}	Sound	d_{1-2}
	f_0	f_{1-2}
	Sound or d_{1-2}	d_{3-6}
	f_0	f_{3-6}
	f_{1-2}	f_{3-6}
	Sound	f_0
New f_0	Sound	f_0
New m	Sound, d_{1-2} , d_{3-6} , f_0	M

Notes: Description of the coding system is described in Ismail *et al.* (2007). There are potentially 182 mutually exclusive tooth surfaces included on the ICDAS examination form.

Sound: 00, un-erupted at W1.

* d_{1-2} : non-cavitated caries lesions on unrestored, sealed, or restored tooth surfaces.

d_{3-6} : cavitated or dentinal lesions on unrestored, sealed, or restored tooth surfaces.

f_0 : Filled tooth surfaces with no recurrent or primary caries.

f_{1-2} : Filled tooth surfaces with non-cavitated caries lesions.

m: Missing due to caries.

variables for health-influencing behaviors such as brushing frequency (with or without toothpaste) during the preceding week (< 7 or ≥ 7), the frequency of using a cloth to wipe the teeth or mouths of children (1 = never or rarely, 2 = sometimes or usually), and type of children's dental visits during the study period (Table 3). Children were classified into "no dental visit", "preventive-only dental visit", and "treatment visit" based on Medicaid dental claims records during the study period. The "no dental visit" group included children with no Medicaid record (n = 90).

Family-level Factors

Parenting stress score measured by an existing scale (Abidin, 1995) was constructed by averaging responses to 6 items and dichotomizing the scores (< 75th percentile or ≥ 75th percentile). The parenting stress score showed a high level of internal consistency (alpha = 0.76) in previous analyses (Finlayson *et al.*, 2007a,b). Depressive symptoms of caregivers were measured according to the Center for Epidemiological Studies Depression Scale (CES-D) (Radloff, 1977; Husaini *et al.*, 1980). CES-D scores were dichotomized into < 23 or ≥ 23, with a score of 23 or greater indicating the presence of depressive symptoms (Siefert *et al.*, 2007). Caregiver's baseline caries was assessed by the d_{1-6} mfs score and further categorized by the quartile values.

The social environment factors at the family level included annual household income (1 = less than \$10,000, 2 $\geq$ \$10,000), highest level of education attained by the caregiver (1 = less than high school, 2 = high school diploma or more), frequency of moving during the preceding 5 yrs (1 = none, 2 = one time, 3 = two or three times, 4 = four or more times), full-time employment status (1 = yes, 2 = no), a measure of religiosity (1 = not religious at all, 2 = not too religious, 3 = fairly religious, 4 = very religious), perceived discrimination, and social support (Siefert *et al.*, 2007). The measure of everyday discrimination assessed the frequency of unfair treatment a caregiver felt that he or she had received according to an 11-item scale ($\alpha = 0.85$). Items included the frequency with which the caregiver was treated with less courtesy, less respect, received poorer service, was called names or insulted, and was unfairly stopped or questioned by police. The items (scale of 1 = "never" to 6 = "almost every day") were summed then dichotomized (< 75th percentile or $\geq$ 75th percentile). Availability of support was measured in four areas, including errands, child care, financial assistance, and help with transportation (Finlayson *et al.* 2007a). A variable was created to identify caregivers with support in all four areas.

To assess health-influencing behavior, we included brushing frequency of the caregiver's teeth (with or without toothpaste) during the preceding week. Caregiver's belief in oral health fatalism was assessed by rating agreement on a five-point Likert-type scale with the statement, "Most children eventually develop dental cavities". The answers were dichotomized (1 = neutral, disagree, or strongly disagree; 2 = agree or strongly agree). To capture various aspects of caregiver oral hygiene knowledge and self-efficacy, we constructed knowledge about bottle use (KBU), children's oral hygiene needs (KCOH), and oral health self-efficacy (OHSE) as described in a previous study of the same population (Finlayson *et al.*, 2005).

Physical environment was measured by whether or not the house had cracks in any walls and if there was a water purifier/filter on the kitchen tap. We assessed the availability of dental services by asking caregivers to rate the availability of dental services for themselves and their families (1 = excellent to 6 = very bad). Whether or not the caregiver's most recent dental visit was for preventive services was also included in the model.

Community-level Factors

The community-level determinants of children's oral health consisted of the number of dentists, churches, and grocery stores, as determined by geocoding (Tellez *et al.*, 2006), in the neighborhoods in which the caregiver and the child live. A neighborhood disadvantage index was computed according to the formula suggested by Ross and Mirowsky (2001) (Cronbach's $\alpha =$

Table 3. Percentage of Children and Caregivers by Predictors Included in the Analysis (n = 788)

Level of influence	Predictors of child's oral health	N (weighted %)
Child-level of influence	Soda consumption	
	None	332 (44.1)
	1 day per week	246 (30.9)
	2-6 days per week	93 (11.8)
	Every day per week	117 (13.3)
	Children's age: weighted mean (S.E.)	2.6 (0.1)
	Weight-for-age percentile	
	1: 0-26.9%	198 (25.7)
	2: 27.0-56.4%	196 (24.5)
	3: 56.7-84.2%	197 (23.8)
	4: 84.3-100%	197 (26.1)
	Ever diagnosed with asthma	
	No	648 (80.7)
	Yes	140 (19.3)
	Currently participating in Head Start	
	No	679 (85.0)
	Yes	109 (15.0)
	Currently participating in WIC	
	No	397 (48.6)
	Yes	391 (51.4)
	Children's gender	
	Male	372 (50.6)
	Female	416 (49.4)
	Type of children's dental visit	
	No visit or no Medicaid record	438 (57.2)
	Preventive visit	216 (26.5)
	Treatment visit	134 (16.3)
	Brushing frequency during preceding week	
	< 7	297 (37.7)
	≥ 7	491 (62.3)
	Frequency of wiping teeth of children	
	Never or rarely	520 (66.6)
	Sometimes or usually	268 (33.4)
	Baseline caries	
	None	428 (54.9)
	< 7	167 (20.8)
	≥ 7	193 (24.3)
Family-level influence	Fatalistic belief	
	No	177 (23.3)
	Yes	611 (76.7)
	Bottle use knowledge: weighted mean (SE)	3.96 (0.1)
	Knowledge of children's oral health: weighted mean (SE)	4.53 (0.0)
	Self-efficacy	
	Low	564 (70.0)
	High ($\geq$ 75th %)	224 (30.0)
	Depressive symptoms	
	Low	633 (80.5)
	High (CESD $\geq$ 23)	155 (19.5)
	Discrimination	
	Low	550 (70.7)
	High ($\geq$ 75th %)	238 (29.3)
	Parenting stress	
	Low	544 (67.7)
	High ($\geq$ 75th %)	244 (32.3)

(continued)

Table 3. (continued)

Level of influence	Predictors of child's oral health	N (weighted %)
Community-level influence	Social support	
	Low	269 (34.4)
	High: support from all five areas	519 (65.6)
	Caregiver's preventive visit	
	No	364 (45.4)
	Yes	424 (54.6)
	Household Income	
	< \$10K	353 (44.9)
	≥ \$10K	435 (55.1)
	Education	
	Less than high school	361 (46.0)
	High school degree or higher	427 (54.0)
	Full-time employment	
	No	538 (67.6)
	Yes	250 (32.4)
	Religiosity ^a : weighed mean (SE)	2.80 (0.0)
	Evaluation of dental services ^b : weighted mean (SE)	4.02 (0.1)
	Brushing frequencies during preceding week	
	< 7	173 (21.4)
	≥ 7	615 (78.7)
	Baseline caregiver's caries (DMFS)	
	1: 0 ~ 27	184 (24.3)
	2: 28 ~ 40	210 (25.7)
	3: 41 ~ 59	192 (23.7)
	4: 60 ~ 182	202 (26.3)
	Moves during preceding 5 yrs	
	None	197 (24.2)
	1	215 (26.1)
	2 - 3 times	193 (24.7)
	4 or more times	183 (25.0)
	Water purifier/filter on kitchen tap	
	No	672 (86.1)
	Yes	116 (13.9)
	Cracks in wall	
	No	509 (64.5)
	Yes	279 (35.5)
	Neighborhood index	
	1 most disadvantaged	183 (24.5)
	2	243 (30.1)
	3	187 (21.6)
	4 least disadvantaged	175 (23.8)
	Number of grocery stores	
	Low	474 (56.7)
	High (≥ Median)	314 (43.3)
	Number of dentists	
	Low	405 (45.4)
	High (≥ Median)	383 (54.6)
	Number of churches	
	Low	413 (53.0)
	High (≥ Median)	375 (47.0)

^a Religiosity (1 = not religious at all, 2 = not too religious, 3 = fairly religious, 4 = very religious).

^b Self-rating of the availability of dental services: 1 = excellent, 2 = very good, 3 = good, 4 = fair, 5 = bad, 6 = very bad.

0.74 in this sample). This index was categorized into four quartiles (1 = most disadvantaged community to 4 = least disadvantaged community).

Statistical Analysis

The association between the predictors and the caries increments was modeled by zero-inflated negative binomial regression (ZINB), which is the appropriate model for analysis of an outcome measure with a high proportion of zeroes (no new carious surfaces developed in this case) (Bulsara *et al.*, 2004). We first carried out a backward elimination model selection to determine the most parsimonious predictive model. We began with the full model, which included all of the oral health predictors in children, family, and community levels, proceeding at each step by dropping from the model variables with p-values > 0.20. The process was repeated until p-values of all variables in the model were less than 0.20. Only those factors identified in the stepwise regression as having a p-value < 0.20 were included as predictors in the subsequent and final zero-inflated negative binomial regression models. In addition, we computed pseudo-R-squared coefficients to summarize the predictive power of the regression models. Similar to the R-square of ordinary least-squares regression, the normalized measure based on restricted and unrestricted maximized log-likelihood ratios was computed for the models developed in this analysis (Cragg and Uhler, 1970). This type of measure describes the power of the explanatory variables (oral health determinants) to predict the dependent variable (increments of $d_{3-6}mfs$ and $d_{1-6}mfs$ in this case) (Agresti, 2002).

Statistical analyses were conducted with STATA version 10 to account for the clustering effect due to the complex sample design (STATA, 2007). All analyses were adjusted with the weight developed to account for unequal selection probabilities and differential non-response. For the small number of missing values (less than 4%) for any individual item on independent variables, values were imputed with *IVWare* software before modification, to create dummy variables (Raghunathan *et al.*, 2001).

RESULTS

Over 96% of the caregivers were female, and the average age was 29.1 yrs at baseline (Table 1). Almost half reported an annual household income of less than \$10,000, placing them in poverty status in the U.S. The majority (67.6%) of caregivers were either unemployed or not employed full-time. The children were equally divided between males and females. Almost 25% of the children had

Table 4. Estimated Incidence Rate Ratios (IRR) and Standard Errors (SE) from the Stepwise (Backward Selection) Zero-inflated Negative Binomial Models for Children's Increment of d_{1-6} mfs and d_{3-6} mfs

	New d_{1-6} mfs			New d_{3-6} mfs		
	IRR	95% CI	p-value	IRR	95% CI	p-value
<i>Child-level predictors</i>						
Soda consumption			0.05			0.03
None (ref)	—	—		—	—	
1/day	0.9	0.7–1.0		1.1	0.7–1.6	
2-6/day	1.5	1.1–2.0		1.9	1.3–2.9	
Every day	1.1	0.9–1.4		1.2	0.8–1.8	
Child's age	0.8	0.7–0.9	0.001	0.7	0.6–0.8	< 0.001
Weight for age percentile			0.03			0.14
0-26.9% (ref)	—	—		—	—	
27.0-56.4%	0.8	0.7–1.0		0.6	0.4–1.0	
56.7-84.2%	1.0	0.8–1.2		0.8	0.5–1.2	
84.3-100%	0.8	0.6–1.0		0.7	0.4–1.1	
Current WIC participation						0.12
No (ref)	—	—		—	—	
Yes				0.8	0.6–1.1	
Current Head Start participation			0.08			0.02
No (ref)	—	—		—	—	
Yes	0.8	0.7–1.0		0.6	0.5–0.9	
Gender						0.02
Male (ref)	—	—		—	—	
Female				1.3	1.0–1.7	
Dental visits			< 0.001			< 0.001
No visit or No Medicaid record (ref)	—	—		—	—	
Preventive visit	1.1	0.9–1.3		1.2	0.9–1.6	
Treatment visit	1.7	1.4–2.0		3.0	2.1–4.2	
Baseline caries level			< 0.001			< 0.001
None (ref)	—	—		—	—	
Baseline caries: < 7	1.6	1.2–2.0		3.7	2.6–5.2	
Baseline caries: ≥ 7	2.3	1.6–3.2		9.3	5.2–16.8	
<i>Family-level predictors</i>						
High bottle use knowledge (KBU)				0.9	0.8–1.0	0.12
Fatalistic belief			0.02			0.04
No (ref)	—	—		—	—	
Yes	1.3	1.1–1.6		1.4	1.0–1.9	
Education level			0.12			
Less than high school (ref)	—	—		—	—	
High school degree or higher	1.1	1.0–1.3				
Full-time employment						0.13
No (ref)	—	—		—	—	
Yes				0.8	0.6–1.1	
Baseline caries level			0.03			0.04
1 (lowest) (ref)	—	—		—	—	
2	1.1	0.9–1.3		0.9	0.6–1.3	
3	1.3	1.0–1.6		1.1	0.7–1.5	
4 (highest)	1.4	1.1–1.9		1.7	1.0–2.8	
<i>Community-level predictors</i>						
Neighborhood index			0.03			
1 (most disadvantaged) (ref)	—	—		—	—	
2	0.9	0.7–1.1				
3	0.7	0.6–0.9				
4 (most advantaged)	0.9	0.7–1.2				
Cragg & Uhler's maximum likelihood R^2	18.7%			23.1%		

Notes: Refer to the text and Table 2 for definition of the factors. Variables were selected via the backward elimination model selection method. Stepwise selection used $p < 0.2$ as the criterion for a variable to be considered in the model. Significance level was set at $P < 0.05$ for the predictors included in the models. Interactions were included in the model. Significant interactions are presented in Appendix Table 6.

lower weight-for-age than the national standard, based on the Centers for Disease Control and Prevention growth chart (Kuczmarski *et al.*, 2000) (data available from the authors).

The factors included in the stepwise regression are listed in Table 3. For all factors, there are sufficient sample sizes of children or caregivers in each of the subcategories for the determinants included in the model.

The zero-inflated negative binomial regression models identified the following factors as significant predictors ($p < 0.05$) of increments in d_{1-6} mfs: higher consumption of soda drinks, older child age, higher weight-for-age, visiting a dentist for treatment, higher baseline caries level of the child and caregiver, fatalistic belief of the caregiver, and living in relatively disadvantaged low-income neighborhood (Table 4). For d_{3-6} mfs increment, the significant predictors were higher consumption of soda drinks, older child age, higher weight-for-age, current participation in Head Start, being female, visiting a dentist for treatment, higher baseline caries level of the child, and fatalistic belief of the caregiver. Interactions among selected key factors were tested (Appendix Table 6), and they did not change the primary findings of the model.

DISCUSSION

Like all studies that rely on subjective data requiring recall of past experiences or behavior, this study may suffer from biases. The association reported in this study may be underestimated. The model tested in this analysis identified several predictors that explain about 20% of the variations in caries increment.

This paper presents findings from the first cohort study of low-income African-American children and caregivers in Detroit, Michigan. Most of the evidence on determinants or predictors of caries has emerged from cross-sectional studies. This analysis, in addition to using a longitudinal design, was conducted with a conceptual model that included social, behavioral, demographic, and other determinants of caries in children. The findings of this analysis confirm those found in cross-sectional analyses of the same baseline data.

The frequent consumption of soda drinks was associated with caries severity at baseline (Burt *et al.*, 2006; Kolker *et al.*, 2008). Caregivers' caries status was modestly correlated with their children's caries status (Reisine *et al.*, 2008).

The association with weight-for-age was inconsistent and did not follow a clear dose-response relationship. A previous analysis of the W1 data found no association between caries and "obesity" (Ramaswami, 2005).

As expected, children who had a dental visit for treatment were more likely to have higher mean caries increments than those who did not visit a dentist, because children in this population seek care when there is a dental problem. Consistent with previous studies, the baseline caries level was a strong predictor of future caries increment (Helfenstien *et al.*, 1991).

Fatalistic beliefs of the caregivers about oral health have been a consistent correlate (Finlayson *et al.*, 2007a,b) and, in this study, a predictor of future caries increment. Dental fatalism was measured with a one-item question of agreement with the statement that "Most children eventually develop dental cavities". Given the predictive power of this one item, it would not only be useful in caries management, but also simple to administer in a clinical or public health practice.

While access to care receives so much attention, it may not be the only important factor associated with caries; rather, this study identified several social and community factors (*i.e.*, neighborhood disadvantage, caregivers' dental fatalism, dental treatment, baseline caries of caregivers and children, and soda consumption) as important predictors of caries development and progression. Failure to consider the social and behavioral determinants of dental caries in preventive programs will lead to failure in this high-risk population.

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