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ORIGINAL MANUSCRIPT

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Development of toolkits for detecting dental caries and caries experience among children using self-report and parent report

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Abstract

Objectives: To develop child- and parent-reported toolkits for active caries and caries experience in children and adolescents, ages 8-17.

Methods: A sample of 398 child/parent dyads recruited from 12 dental practices in Los Angeles County completed a computer-assisted survey that assessed oral health perceptions. In addition, children received a dental examination that identified the presence or absence of active caries and caries experience. A Multiple Adaptive Regression Splines model was used to identify a subset of survey items associated with active caries and caries experience. The splines and coefficients were refined by generalized cross-validation. Sensitivity and specificity for both dependent variables were evaluated.

Results: Eleven child self-reported items were identified that had sensitivity of 0.82 and specificity of 0.45 relative to active caries. Twelve parent-reported items had a sensitivity of 0.86 and specificity of 0.50. Seven child self-reported items had a sensitivity of 0.86 and specificity of 0.34, and 11 parent-reported items had a sensitivity of 0.86 and specificity of 0.47 for caries experience.

Conclusions: The survey items identified here are useful in distinguishing children with and without active caries and with and without caries experience. This research presents a path towards using children's and their parents' reports about oral health to screen for clinically determined caries and caries exposure. The items identified in this study can be useful when clinical information is unavailable.

KEYWORDS

caries, caries risk, health services research, oral health, paediatric dentistry

1 | INTRODUCTION

Dental caries is a multifactorial disease endemic in many countries and has a high prevalence in children and adolescents in the United States.[1] In the United States between 2011 and 2014, 18.6% of children and adolescents had untreated caries[2] The cost per child 2-17 years old receiving care in 2003, not including orthodontic treatment, is estimated to be $336 in 2019.[3] In 2008, an estimated 34 million hours of school were lost among those 5-17 years old due to acute or unplanned dental visits.[4] Dental caries is a significant problem both in terms of prevalence of disease and economic impact on children and adolescents and their families.

Dental research of children's and parent's perceptions primarily concern oral health status and need for dental treatment. A large study of employees of two insurance companies revealed that the number of carious teeth was significantly associated with perceived oral health, but filled teeth were not.[5] Overall, missing and decay teeth accounted for only 14% of the variation in oral health status. Untreated decay among adolescents was found to be significantly associated with both parental and adolescent perceptions of oral health and need for treatment in another study.[6] Caries experience was significantly associated with parental but not adolescent oral health perceptions.

JT Divaris[7] published an in-depth analysis of the complexities of predicting early childhood caries outcomes and concluded that the tools developed have limited clinical utility, but are a resource for training clinicians, informing parents and guiding public health programmes. Such caries risk assessment systems (CRAs) contain items derived from expert opinion including clinical measures such as caries, microflora and salivary pH and flow. CRAs also may include information about patients' access to care and their sociodemographic characteristics. In a review of major CRAs, found 'wide variations in caries-related risk categories' only, the Cariogram system used combined sensitivity and specificity to evaluate prediction of caries in permanent teeth. The authors concluded that the validity of existing CRAs is limited and that more reliable CRAs methods are needed.[8]

While it is difficult to estimate the presence of active caries in individual children, in this study we evaluate the use of children's and their parents/guardians' perceptions of oral health as the basis for further understanding their relationship to the presence of oral disease. We evaluate the sensitivity and specificity of survey items administered to children and their parents/guardians to two dichotomous measures of caries from a dental examination of a sample of children 8-17 years old: 1) active caries (ie one or more decayed teeth) and 2) caries experience (decayed, filled or missing teeth). The study provides information relevant to identifying children with caries risk when dental examination data are unavailable.

In our research, an item pool was developed to assess oral health status.[9-12] We used the Children's Oral Health Status Index (COHSI) and dentists' referral recommendations (RR) as dependent measures.[13,14] In a previous paper, factor analysis and IRT based on 334 children and adolescents were used to develop a 12-item short form, consisting of 8 for the COHSI and 7 for the RR with 3 items that were common to both.[13] Even with the ability to estimate the COHSI score, it was not specific enough to identify children's need for dental care. Since the COHSI score is based on decayed, missing, filled teeth (DMFT), along with occlusal conditions, the subset of caries-related components can be used to profile each child's active caries and caries experiences.

The methodology in this current paper is based on Patient Reported Outcomes Measurement Information System (PROMIS®). Other PROMIS® studies described patient-reported outcomes (PROs) as tools for clinical intervention used in paediatric palliative care [15]; a PROMIS® smoking assessment toolkit measures 6 domains used in smoking research [16]; and a personal health information toolkit (PHIT) combines self-report and monitoring sensors to address interventions for chronic diseases, risky behaviours, sleep etc.[17]

The objective of this study was to develop child- and parent-reported toolkits for active caries (DT, children who have one or more decayed teeth), and caries experience represented by one or more DMFT.

2 | METHODS

The development of the item banks used in this paper involved several steps including review of existing surveys; conducting focus groups of children, adolescents and parents; cognitive interviews and expert panels.[10,11]

The sample in this study consists of 398 dyads of parents and their children ages 8 to 17 (Table 1). Fifty-nine per cent of the children are in the 8- to 12-year-old age group; gender is almost even (51% male). Forty-three per cent were Hispanic, 12% Asian, 17% mixed race/ethnicity and 9% black. While 90% of children reported speaking English at home, 33% of parents responded that English was not their primary language. Almost three-quarters of parents were female as were those either married or living with a partner; also, three-quarters of the households had one or more fully employed members, while 11% of households.[9,18,19]

Institutional review board approval for this study was obtained from the University of California, Los Angeles Office of the Human Research Protection Program (Institutional Review Board approval 13-001330). Voluntary informed assent and written consent were obtained from children and their parents prior to participation.

2.1 | Clinical examination

Two faculty dentists conducted the examinations at each site. The 'reference examiner' has extensive experience as an examiner for national surveys, clinical research studies and epidemiological surveys. The other examiner is a clinical faculty member with extensive experience in examining patients. They followed the Children's Oral Health Status protocol, which consists of an occlusal section, and a section for examination of primary and permanent teeth for DMFT (copies of the COHSI Exam Manual are available upon request). Each examiner had a recorder who entered the examination data on a laptop. Clinical examinations were performed in dental operatories of

TABLE 1 Sociodemographic characteristics of children and parents (N = 398)

	Sociodemographic characteristics	Number (%)
Child reported	Child age group	
	Children (8 - 12)	235 (59.0%)
	Adolescents (13 - 17)	163 (41.0%)
	Child gender	
	Male	202 (50.7%)
	Female	196 (49.3%)
	Child ethnicity self-reported	
	White	80 (20.1%)
	Black/African American	35 (8.8%)
	Hispanic/Latino	169 (42.5%)
	Asian	47 (11.8%)
	Mixed and other	67 (16.8%)
	Child's language spoken at home	
	English	357 (89.7%)
	Others	41 (10.3%)
Parent reported	Parent gender	
	Male	112 (28.1%)
	Female	286 (71.9%)
	Parent ethnicity	
	White	91 (22.9%)
	Black/African American	37 (9.3%)
	Hispanic/Latino	192 (48.2%)
	Asian	47 (11.8%)
	Mixed and other	31 (7.8%)
	Child ethnicity reported by parent	
	White	69 (17.3%)
	Black/African American	39 (9.8%)
	Hispanic/Latino	180 (45.2%)
	Asian	39 (9.8%)
	Mixed and other	73 (18.3%)
	Parent's primary language	
	English	265 (66.6%)
	Others	133 (33.4%)
	Marital Status	
	Married/living w/partner	296 (74.4%)
	Single	102 (25.6%)
	Family employment	
	Not working	44 (11.1%)
	Part-time job	45 (11.3%)
	Full-time job	309 (77.6%)

participating dental practices. Primary and permanent teeth were recorded as sound, decayed, missing and filled teeth. Filled teeth that contained caries were recorded as carious. Third molars were included in the study. In the training session, the dentists went over the criteria for the clinical examination and conducted examinations on 10 children adolescent whose ages were 2-17. The differences were reconciled through discussion and consensus. At each site, 2 to 3 duplicate examinations were conducted. A total of 52 children were examined by both dentists to check the inter-rater reliability. The agreement was high using both prevalence-adjusted and bias-adjusted Kappa[20] (PABAK, 0.77 for DT and 0.81 for DMFT) and Gwet's AC1[21] (0.86 for DT and 0.81 for DMFT).

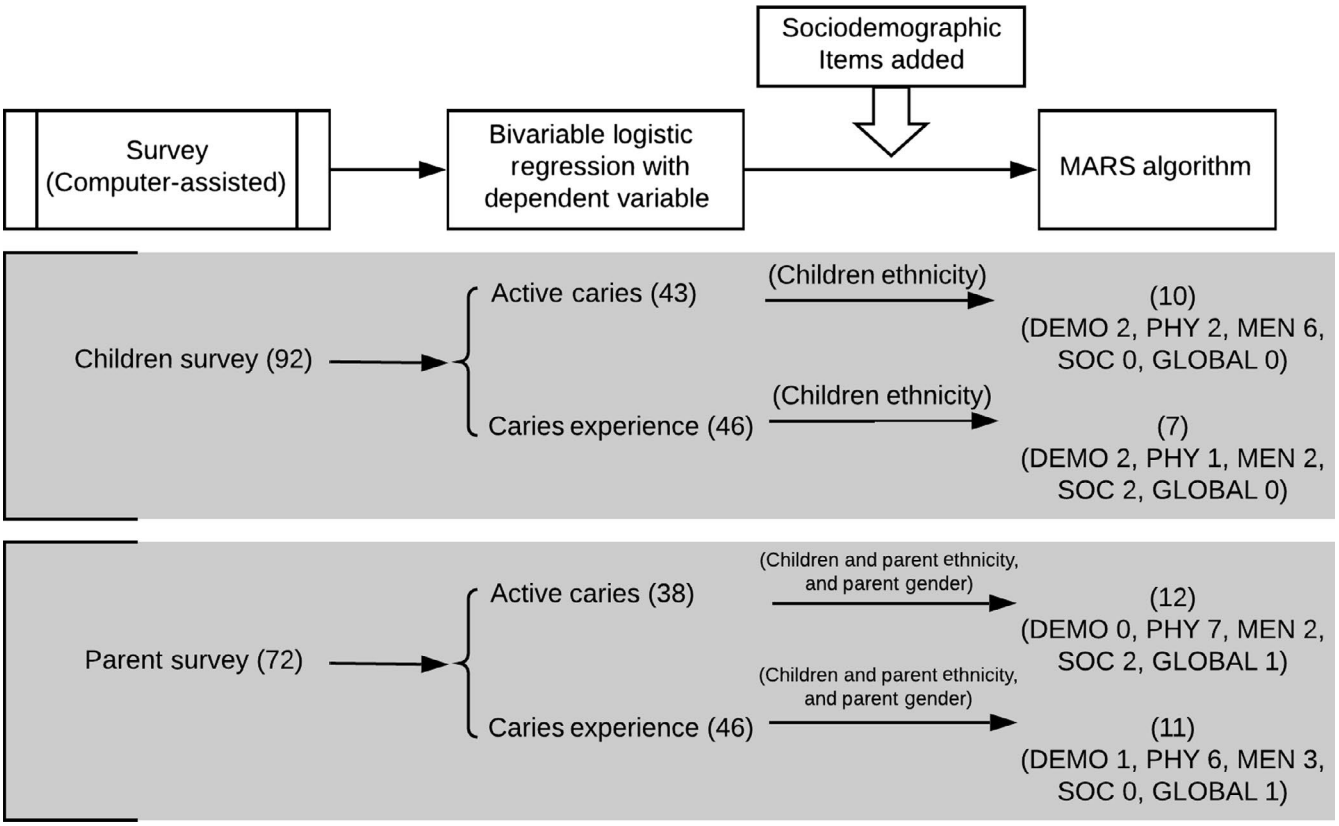

FIGURE 1 Flowchart of development of parent and child's toolkits: active caries (DT)/caries experience (DMFT), analysis method and number of items by Domain. DEMO, sociodemographic; GLOBAL, global; MEN, mental; PHY, physical; SOC, social

2.2 | Statistical models and data analyses

Figure 1 presents a flowchart with the statistical analyses steps. In the child's computer-assisted survey, there are 92 items, 88 of which concern physical, mental, social and global oral health domains; there are also 4 sociodemographic items. The parent's survey has 72 items, 8 of which were sociodemographic. The logistic regression was performed on each item individually. After data rescaled, clinically and socially meaningful variables were expected to have a negative relationship with the response variable (ie DT or DMFT). To obtain a more stable negative coefficient, we applied the idea of 10-fold cross-validation. The logistic regression model was run on 9-fold out of 10-fold each time. The procedure was repeated 10 times for each item. Items which had negative coefficients for all 10 times were our candidate items for a Multiple Adaptive Regression Splines Model (MARS).

The bivariable logistic regression produced results for active caries (DT) and caries experience (DMFT), for children and parents. A total of 43 child self-report items were selected for active caries and 46 for caries experience, while the number of parental proxy items selected was 38 and 46, respectively. Some extra sociodemographic items such as ethnicity of children and parent and parent gender dummy variables that were added back after checking the bivariable logistic regression coefficients because they do not have directionality with regard to the dependent variables.

Then MARS [22] algorithm, a nonparametric regression model that automatically models nonlinearities and interactions, was used. Unlike logistic regression analyses where survey item responses are fitted into a single line, in MARS each response within a survey item is evaluated and several coefficients can be generated for a survey item, providing a more accurate evaluation of the relationships of items with the dependent variables. As part of the MARS analysis, generalized cross-validation was applied to trade-off model complexity and accuracy in order to avoid overfitting. The MARS results for the 2 children and 2 parent models reduced the items further.

3 | RESULTS

The results from the MARS analyses for children are a toolkit for active caries consisting of 10 items: 2 demographic, 2 physical and 6 mental items, but no social and global health domains entered. The caries experience toolkit consists of only 7 items: 2 demographic, 1 physical, 2 mental and 2 social; global health was not included. The parent toolkit for active caries has 12 survey items: 7 are from the physical domain, 2 mental, 2 social and 1 global health; no sociodemographic items entered. The parent toolkit for caries experience has 11 items: 1 demographic, 6 physical, 3 mental and 1 global health; there were no social items. See Appendix S1 for the list of

TABLE 2 Frequency of active caries (DT) and caries experience (DMFT) by sociodemographic characteristic (N = 398)

	Active caries (DT)			Caries experience (DMFT)		
	DT = 0	DT > 0	*P*-value*	DMFT = 0	DMFT > 0	*P*-value*
Overall	347 (87.2%)	51 (12.8%)		177 (44.5%)	221 (55.5%)	
Child age group						
Children (8-12)	203 (86.4%)	32 (13.6%)	NS	93 (39.6%)	142 (60.4%)	.02*
Adolescents (13-17)	144 (88.3%)	19 (11.7%)		84 (51.5%)	79 (48.5%)	
Child gender						
Male	182 (90.1%)	20 (9.9%)	NS	96 (47.5%)	106 (52.5%)	NS
Female	165 (84.2%)	31 (15.8%)		81 (41.3%)	115 (58.7%)	
Child ethnicity						
White	72 (90.0%)	8 (10.0%)	NS	50 (62.5%)	30 (37.5%)	.007**
Black/African American	28 (80.0%)	7 (20.0%)		12 (34.3%)	23 (65.7%)	
Hispanic/Latino	147 (87.0%)	22 (13.0%)		71 (42.0%)	98 (58.0%)	
Asian	41 (87.2%)	6 (12.8%)		18 (38.3%)	29 (61.7%)	
Mixed and other	59 (88.1%)	8 (11.9%)		26 (38.8%)	41 (61.2%)	
Child's language spoken at home						
English	315 (88.2%)	42 (11.8%)	NS	163 (45.7%)	194 (54.3%)	NS
Others	32 (78.1%)	9 (22.0%)		14 (34.2%)	27 (65.9%)	
Parent gender						
Male	98 (87.5%)	14 (12.5%)	NS	48 (42.9%)	64 (57.1%)	NS
Female	249 (87.1%)	37 (12.9%)		129 (45.1%)	157 (54.9%)	
Parent ethnicity						
White	84 (92.3%)	7 (7.7%)	NS	61 (67.0%)	30 (7.5%)	<.001***
Black/African American	29 (78.4%)	8 (21.6%)		11 (29.7%)	26 (70.3%)	
Hispanic/Latino	165 (85.9%)	27 (14.1%)		78 (40.6%)	114 (59.4%)	
Asian	41 (87.2%)	6 (12.8%)		14 (29.8%)	33 (70.2%)	
Mixed and other	28 (90.3%)	3 (9.7%)		13 (41.9%)	18 (58.1%)	
Child ethnicity determined by parent						
White	63 (91.3%)	6 (8.7%)	NS	47 (68.1%)	22 (31.9%)	<.001***
Black/African American	30 (81.1%)	7 (18.9%)		11 (29.7%)	26 (70.3%)	
Hispanic/Latino	158 (87.8%)	22 (12.2%)		74 (41.1%)	106 (58.9%)	
Asian	34 (87.2%)	5 (12.8%)		10 (25.6%)	29 (74.4%)	
Mixed and other	62 (84.9%)	11 (15.1%)		35 (48.0%)	38 (52.1%)	
Parent's primary language						
English	232 (87.6%)	33 (12.5%)	NS	134 (50.6%)	131 (49.4%)	<.001***
Others	115 (86.5%)	18 (13.5%)		43 (32.3%)	90 (67.7%)	
Marital status						
Married/living w/partner	262 (88.5%)	34 (11.5%)	NS	141 (47.6%)	155 (52.4%)	.03*
Single	85 (83.3%)	17 (16.7%)		36 (35.3%)	66 (64.7%)	
Family employment						
Not working	40 (90.9%)	4 (9.1%)	NS	13 (29.6%)	31 (70.5%)	.05*
Part-time job	39 (86.7%)	6 (13.3%)		17 (37.8%)	28 (62.2%)	
Full-time job	268 (86.7%)	41 (13.3%)		147 (47.6%)	162 (52.4%)	

*Chi-square test. NS is equivalent to *P*-value greater than 0.05 level.

children's and parents' items, for the Active Caries toolkits, with distributions of responses. Appendix S2 has the same information for the caries experience toolkits.

Table 2 presents sociodemographic characteristics by active caries and caries experience with the result of the chi-square test. In the overall sample of 398 children and parent dyads, 87% of children had

no active caries at the time of the examination, while 45% of these had never experienced caries (caries-free). When comparing age groups, there was no statistically significant difference in active caries; however, caries experience in the adolescent group had a higher percentage of no caries experience than the 8- to 12-year-olds, 52% vs 40% at the $P = .02$. Neither the children's nor their parents' gender differed significantly by either dependent variable. However, gender was used to estimate the caries experience in the child toolkit. With regard to the child's reported ethnicity, there was no difference in active caries, but whites had the highest rate of no caries experience (63%), while blacks had the lowest (34%); other ethnic groups tended to have percentages in the low forties or high thirties with an overall P value of .01. When the parent reported their child's ethnicity, again there was no difference in active caries, with a similar difference in caries experience ($P < .001$). There was no significant difference in the child's reported language spoken at home with either dependent variable. However, children with parents whose primary language was not English had higher rates of caries experience (68% vs 49%, $P < .001$), but there was no significant difference with regard to active caries. Parents' marital status only showed differences in caries with regard to caries experience; 65% of the children of parents without a spouse or partner had caries experience, compared with 52% for two-parent families ($P = .03$). The employment status of the family was statistically significant for caries experience. Those families with full-time employment have children with the least caries experience and those children who come from families where parents were unemployed had the highest level of caries experience (71% at $P = .05$). These data show that parent-reported sociodemographic variables have more significant differences for caries experience in 7 of the 9 sociodemographic items, while none of the active caries sociodemographic items had significant differences.

Sensitivities and specificities of active caries for both the child and parent toolkits are reported in Table 3. The child toolkit for active caries had a sensitivity of 82% and specificity of 45%, correctly identifying 42 of the 51 children (true positives). In addition, 157 of 347 children were correctly identified as not having active caries (true negatives). The parent sensitivity and specificity percentages were 86% and 50%, respectively, accurately identifying 44 of 51 children with active caries. The estimate for no active caries was 172 of 347. The parent toolkit had a slightly higher sensitivity and specificity than the child toolkit. The specificity for both toolkits was low, with high numbers of false positives.

The results of sensitivities were the same for both the child and parent toolkits with different specificities. The child toolkit had a sensitivity of 86% with specificity of 34%, while the parent toolkit sensitivity was 86% and specificity was 47%. The false negative identified by the child toolkit was 31 and 30 for the parent toolkit. False positive was 116 and 94, respectively. The parent caries experience toolkit correctly identified 20 more children who were free from caries experience.

4 | DISCUSSION

This paper demonstrated an approach to developing toolkits using information selecting from survey items collected from parents about their child and from their children themselves. The child caries toolkit's ability to identify true positives for the presence of active

TABLE 3 Sensitivity and specificity of child, parent and combined toolkits for active caries and caries experience

		Child toolkit			Parent toolkit	
		Active caries				
		Sensitivity	Specificity		Sensitivity	Specificity
		0.82	0.45		0.86	0.50
		Examination results			Examination results	
		No active caries	Active caries		No active caries	Active caries
Model predictions	No active caries	157 (39.4%)	9 (2.3%)	No active caries	172 (43.2%)	7 (1.8%)
	Active caries	190 (47.7%)	42 (10.6%)	Active caries	175 (44.0%)	44 (11.1%)
		Caries experience				
		Sensitivity	Specificity		Sensitivity	Specificity
		0.86	0.34		0.86	0.47
		Examination results			Examination results	
		No caries experience	Caries experience		No caries experience	Caries experience
Model predictions	No caries experience	61 (15.3%)	31 (7.8%)	No caries experience	83 (20.9%)	30 (7.5%)
	Caries experience	116 (29.1%)	190 (47.7%)	Caries experience	94 (23.6%)	191 (48.0%)

caries (true positives) was reasonable high, over 80%, but it also identified many children who did not have active caries as false positives over 50%. It is also possible to improve the active caries estimation to 90%, but the false positives would increase to over 75%. The efficacy of a set of survey items lies in its ability to accurately identify the condition of interest at a high level, while keeping the false positives to a minimum. It is important to note that in this research we are using child and parent preceptions to estimate disease and its effects, which is consistent with the PROMIS® methodology. Parent reports about their children were found to be predictive of active caries. Indeed, the parent toolkits outperformed child ones. Regarding caries experience, the child toolkit only had 7 items; it had the same sensitivity as the 11 parent items (86%). The parents' specificity was 13% higher, reducing false positives.

Considering that caries risk assessment measures caries history and dental care history as risk factors, it is important to identify these children as well.[23] Of course, there are a plethora of other risk factors, including morphology, many of which are impossible to obtain from survey data.

A few studies addressed self-reported dental caries and caries experience evaluated in terms of sensitivity and specificity. A study of 410 Israeli military recruits used a 10-item questionnaire and the results of a clinical examination with bitewing X-rays as the dependent variables. In another study of 123 Israeli recruits, three items were statistically associated with having dental caries and these were as follows: 'My gums tend to bleed when I brush my teeth;' 'I think my teeth are getting worse despite my daily brushing;' and 'I put off going to the dentist until I have a toothache.'[24,25] Although these items showed significant association with dental caries, their ability to identify those with dental caries was not estimated. A comparison between a clinical examination and self-reported dental caries, using a 24-item survey in a cohort of 1,014 Brazilian eighteen years old, found a mean dental caries rate by the examination of 0.79 compared with a self-reported rate of 0.63. The authors only reported prevalence ratios (caries experience rates) with sensitivity of 81% and specificity of 78%.[26] A question remains of how well our toolkits would function on populations that have high levels of active caries, such as those examined in the Brazilian study or less restricted samples such as the Israeli recruit studies.

The item banks developed as part of this work enabled us to draw from a broad base of questions that included physical, mental, social domains and demographic characteristics which were identified as candidates for the toolkits. The use of the COHSI enabled the research to address issues of oral health status in children, as well as providing traditional dependent variables for caries and caries experience. This paper explores toolkit development that can serve as a guide to dental disease toolkits using its analytical approach as well as its findings.

The focus of our original data pool items was developed not to detect dental disease incidence and prevalence but assess oral health status. To remedy this, recently, we added new items that enable the respondents to directly report on the presence of caries, fillings and missing teeth by having photographic examples of these conditions. Visual support is available, such as computerized illustrations and hand-held mirrors. We are currently testing this, and preliminary findings based on two field testing indicated that the addition of these items would increase the accuracy of the survey in terms of developing caries and caries experience toolkits. Future studies will incorporate disease-related items, while maintaining the oral health components.

Another limitation of the study is that the child-parent dyads were drawn for users of dental care in various types of practices. Our sample lacks those who are not users of dental care and are likely to be more impacted by dental caries. This study does not predict active caries or caries experience, because these findings are based on cross-sectional data only. Rather, we are examining associations at this time.

The potential of this study is that it lays the foundation for developing toolkits that enable practices, schools and community organizations to identify those children who require more intensive outreach to ensure that their risk of active disease is treated than those children who may not have active disease but are at higher risk can be identified for preventive measures. In effect, these toolkits may enable population outreach so that measuring oral health in children can be more cost-effective. It will also be necessary to conduct longitudinal studies that are applied to a variety of populations with different rates of active caries and have different levels of access to dental services.

It is impossible to split the data set for appropriate items selection, training the algorithm for stable parameters and test the generalizability of the toolkits. However, our study still demonstrates the utility of the disease-targeted items that have great potential for improving the sensitivity and specificity of the toolkits that target active caries and caries experience. Further research, including the disease-oriented items with a large study population, could enhance the algorithms and generalizability of the results, together with longitudinal follow-up to determine the ability of these toolkits to estimate active caries and caries experience.

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AUTHOR CONTRIBUTIONS

(1) Marvin Marcus, Honghu Liu, Carl Maida, Di Xiong and Yan Wang were initially responsible for the conceptualization and design of the project. Ron Hays, Ian Coulter, Vladimir Spolsky, Steve Lee and James Crall made substantial contributions to the further

development of the concept and its application to the design and interpretation of the analyses. D. Xiong, Y. Wang, M. Marcus, H. Liu, C. Maida and J. Shen made substantial and innovative contributions to the various analytical approaches and interpretations of data that were collected by the larger group. (2) M Marcus, D Xiong, Y Wang and C Maida drafted this article. RD Hays, VW Spolsky, H Liu, ID Coulter, SY Lee, JJ Crall and J Shen made major contributions to the writing of the manuscript including revising and contributing critical and intellectually important content. 3) All listed authors gave final approval of the current version to be published.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of the article.

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