Journal of Dental Research
2023, Vol. 102(9) 988–998
© International Association for Dental, Oral, and Craniofacial Research and American Association for Dental, Oral, and Craniofacial Research 2023
Article reuse guidelines:
sagepub.com/journals-permissions
DOI: 10.1177/00220345231173585
journals.sagepub.com/home/jdr

Predicting Dental Caries in Young Children in Primary Health Care Settings

M. Fontana[1], G.J. Eckert[2], B.P. Katz[3], M.A. Keels[3], B.T. Levy[4], S.M. Levy[4], A.R. Kemper[5], E. Yanca[1], R. Jackson[2], J. Warren[4], J.L. Kolker[4], J.M. Daly[4], S. Kelly[3], J. Talbert[4], and P. McKnight[6]

Abstract

Young children need increased access to dental prevention and care. Targeting high caries risk children first helps meet this need. The objective of this study was to develop a parent-completed, easy-to-score, short, accurate caries risk tool for screening in primary health care settings to identify children at increased risk for cavities. A longitudinal, prospective, multisite, cohort study enrolled (primarily through primary health care settings) and followed 985 (out of 1,326) 1-y-old children and their primary caregivers (PCGs) until age 4. The PCG completed a 52-item self-administered questionnaire, and children were examined using the International Caries Detection and Assessment Criteria (ICDAS) at 12 ± 3 mo (baseline), 30 ± 3 mo (80% retention), and 48 ± 3 mo of age (74% retention). Cavitated caries lesion (dmfs = decayed, missing, and filled surfaces; d = ICDAS ≥3) experience at 4 y of age was assessed and tested for associations with questionnaire items using generalized estimating equation models applied to logistic regression. Multivariable analysis used backward model selection, with a limit of 10 items. At age 4, 24% of children had cavitated-level caries experience; 49% were female; 14% were Hispanic, 41% were White, 33% were Black, 2% were other, and 10% were multiracial; 58% enrolled in Medicaid; and 95% lived in urban communities. The age 4 multivariable prediction model, using age 1 responses (area under the receiver operating characteristic curve = 0.73), included the following significant ($P < 0.001$) variables (odds ratios): child participating in public assistance programs such as Medicaid (1.74), being non-White (1.80–1.96), born premature (1.48), not born by caesarean section (1.28), snacking on sugary snacks (3 or more/d, 2.22; 1–2/d or weekly, 1.55), PCG cleaning the pacifier with juice/soda/honey or sweet drink (2.17), PCG daily sharing/tasting food with child using same spoon/fork/glass (1.32), PCG brushing their teeth less than daily (2.72), PCG's gums bleeding daily when brushing or PCG having no teeth (1.83–2.00), and PCG having cavities/fillings/extractions in past 2 y (1.55). A 10-item caries risk tool at age 1 shows good agreement with cavitated-level caries experience by age 4.

Keywords: risk factors, cariology, personalized medicine, cohort study, pediatrics, pediatric dentistry

Introduction

Dental caries is one of the most prevalent chronic noncommunicable diseases and unmet health care needs among children (Kassebaum et al. 2015), particularly poor and minority children (Dye et al. 2015). Few young children have adequate access to dental care (U.S. Department of Health and Human Services 2020); thus, medical providers have been urged to help with referrals and prevention (American Academy of Pediatrics [AAP] Section of Pediatric Dentistry and Oral Health 2008; U.S. Preventive Services Task Force [USPSTF] 2021). Yet, substantial disparities and inequities in caries among children persist (National Institutes of Health 2021). Current guidelines (USPSTF 2021) conclude that although important, there is a lack of evidence to recommend caries screening for young children by primary care clinicians.

Numerous cost-effective strategies are available to prevent and/or arrest early stages of this disease process (Weyant et al. 2013). Yet if caries lesions are allowed to progress, they can be expensive to treat, in some cases involving sedation or general anesthesia. Untreated cavitated lesions can result in pain and infection, with lasting negative impacts on function, nutrition, sleep, growth and development, self-esteem, school performance and attendance, and so on (Singh et al. 2020).

[1]University of Michigan, Ann Arbor, MI, USA
[2]Indiana University, Indianapolis, IN, USA
[3]Duke University, Durham, NC, USA
[4]University of Iowa, Iowa City, IA, USA
[5]Division of Primary Care Pediatrics, Nationwide Children's Hospital, Columbus, OH, USA
[6]George Mason University, Fairfax, VA, USA

A supplemental appendix to this article is available online.

Corresponding Author:
M. Fontana, University of Michigan, 1011 North University, Ann Arbor, MI 48109, USA.
Email: mfontan@umich.edu

Targeted health care delivery can be an important strategy to improve health and patient-centered outcomes, while containing costs (Fontana et al. 2020; Burgette et al. 2021). However, most caries risk assessment (CRA) tools are expert informed, with limited evaluation or validation (Mejàre et al. 2014; Cagetti et al. 2018; Fontana et al. 2020). The objective of this study was to develop a practical and easily scored short CRA tool for use in primary health care settings. It was hypothesized that a parent-administered questionnaire could help predict whether 1-y-old children will develop cavitated lesions by the time they are in preschool.

Methods

This longitudinal prospective, multicenter cohort study collected data between 2012 and 2017 and enrolled 1-y-old children, following them until age 4. This observational study conformed to Strengthening the Reporting of Observational Studies in Epidemiology guidelines. Three primary care medical research networks (Pediatric Research Network in Indianapolis, IN; Iowa Research Network in Iowa City, IA; and Duke University's Primary Care Practice-Based Research Network in Durham, NC) enrolled 1,326 children (age at baseline = 12 ± 3 mo). The University of Michigan was the data coordinating center. The study was approved by the institutional review boards at all 4 universities. Written consent was obtained from the parent/legal guardian.

A convenience sample was identified primarily through well-child medical appointments, but other venues were also used (e.g., neighborhood centers, daycares, and advertising). Children were scheduled for in-person visits at approximately age 1, 2.5, and 4 y. To enhance retention and check for access to dental care, intermediate contacts (e.g., by phone, mail, email) occurred every 4 mo, with yearly birthday postcards.

Each child was paired with their primary caregiver (PCG), defined as the individual primarily responsible for the child's housing, health, and safety. For recruitment purposes, PCGs were limited to those who were also the parent/legal guardian and lived in the same residence as the child. Inclusion criteria were PCG being ≥18 y old or an emancipated minor; able to read and speak English and/or Spanish; provide written, informed consent for themselves and child; complete the risk questionnaire; and be available for follow-up visits and contacts. The child had to be 12 ± 3 mo old, generally healthy, and allow intraoral examination. Exclusion criteria included being in foster care, requiring antibiotic and/or sedative premedication prior to dental exam, a history of uncontrolled epilepsy, undergoing cancer therapy, or having an unrepaired congenital heart defect.

During each in-person clinical visit, the PCG completed a self-administered 52-item CRA questionnaire, developed from existing medical/dental CRA instruments and the literature as previously described (Fontana et al. 2019). Each child received a dental examination conducted by a calibrated dentist/dental hygienist who was blinded to questionnaire responses (Fontana et al. 2019). Teeth were cleaned with a toothbrush, dried, and assessed under light (Orascoptic Endeavour headlamps), without magnification, using the International Caries Detection and Assessment System (ICDAS 2020) criteria for scoring caries. No dental radiographs were taken. At every visit, PCGs were informed of findings and given preventive care instructions. The ICDAS criteria are a predominantly visual set of codes based on the characteristics of clean, dry teeth, capable of assessing caries severity.

Each site had a primary and backup examiner (in case the primary examiner was unavailable), who were calibrated yearly against the ICDAS criteria. Acceptable intra- and inter-examiner reliability was defined as $\kappa \geq 0.7$ for ICDAS scores 5 to 6, with κ values also assessed for ICDAS ≥3.

The primary study outcome at the participant level included incidence of cavitated caries lesion experience (d3mfs = decayed, missing, and filled surfaces; d = ICDAS ≥ 3) and/or progression of existing cavitated-level caries experience (change from ICDAS = 3–4 to 5–6, or filling, or missing due to caries) at follow-up. This threshold was chosen to identify lesions that would not be managed in a medical setting and require referral.

Sample size calculations assumed 30% cavitated caries experience by age 4, 45% attrition, and CRA tool sensitivity = 80% (95% confidence interval [CI], 75%–85%) and specificity = 85% (95% CI, 82%–88%). Calculations also were designed to have 80% power to detect 10% to 20% differences in sensitivity and specificity between subgroups based on Medicaid/non-Medicaid and race/ethnicity.

Statistical Analyses

Cavitated caries experience at age 4 was tested for associations with questionnaire items using generalized estimating equation (GEE) models applied to logistic regression to account for study site clustering. Multivariable analysis used stepwise model selection, with a limit of 10 predictors included in the final model, as the goal was a brief tool to aid in implementation. Starting with all variables within each domain included in a domain-specific model, a backward selection technique removed nonsignificant predictors. Significant predictors ($P < 0.05$) were then combined into a single model, and backward selection was again used to determine the final model. Odds ratios with 95% CIs were calculated for each predictor. To simplify implementation, a point value was assigned to each variable based on its β-coefficient from the final model, and point values from each variable were summed to calculate a risk score. The ability of the original model and the risk score to discriminate between patients with and without caries was evaluated by the area under the receiver operator characteristic (ROC) curve (AUC). Additional statistics for evaluation of the risk score include the probability of having caries for each score and sensitivity, specificity, positive and negative likelihood ratios, and positive and negative predictive values using each score as a cutoff for predicting caries by age 4.

Additional risk scores were created by repeating the modeling steps above for subgroups based on Medicaid enrollment to

Table 1. Enrollment and Retention of Participants at In-Person Clinical Examinations.

Characteristic	Indiana University	Duke University	University of Iowa	Total	Retention (%)
Approached (*n*)	869	787	517	2,173	—
Approach/enrolled ratio	1.6	1.8	1.5	1.6	—
Enroll/baseline exam (*n*)	543	434	348	1,325	—
Post 18-mo (2.5 y of age) exam (*n*)	403	351	307	1,061	80
Post 36-mo (4 y of age) exam (*n*)	386	320	276	982	74
Early termination[a]	150	109	70	329	

[a]Early termination: included participants who elected to withdraw (*n* = 5 too much time needed for study; *n* = 12 moved; *n* = 39 other reasons), were withdrawn by the principal investigator (*n* = 247 unable to have ongoing contact; *n* = 12 other), withdrew due to not being able to complete the baseline caries exam or questionnaire (*n* = 3), or other reasons (*n* = 11).

evaluate whether a single risk score is sufficient to cover all groups. Because implementation may not always take place at 1 y of age, sensitivity analyses were performed 1) by applying the point values to the 2.5-y-old visit responses instead of the 1-y-old visit responses and 2) by repeating the modeling steps to create a separate risk score tool using the 2.5-y-old visit responses. Further, other caries cutoffs (ICDAS ≥1, which includes any cavitated and noncavitated lesion, and ICDAS ≥5, which includes only extensive cavitated lesions) were evaluated as secondary outcomes using 1-y-old and 2.5-y-old responses. Because of discrimination bias concerns with use of race/ethnicity in clinical algorithms, the primary model was run both with and without race/ethnicity.

To reduce the impact of biased results by including only participants who completed the 4-y-old visit, missing data were imputed using the Proc MI procedure in SAS to include participants lost to follow-up. Twenty-five imputed data sets were created using multivariable imputation by fully conditional specification methods via a discriminant function for categorical data and a predicted mean matching regression model for continuous data.

Internal validation of the risk score was evaluated using bootstrap sampling estimates of the AUC (*n* = 1,000 bootstrap samples). Calibration of the risk score was evaluated by calculating the predicted versus observed proportions of subjects with caries at each score using the intraclass correlation coefficient.

All analyses were performed using SAS version 9.4 (SAS Institute).

Results

After consenting, 1,326 PCG–children pairs were enrolled over 16 mo, with 1,325 completing the baseline visit (Table 1). Information on the study cohort and baseline questionnaire responses has been reported previously (Fontana et al., 2019). Briefly, the majority of PCG (94%) were mothers. The infants' (51% males, 49% females) mean (SD) age was 11.4 (2.0) mo at baseline, while the PCGs' was 28.7 (6.0) y, and 61% of children were enrolled in Medicaid. The ethnic/racial distribution of children was as follows (rounded percentage): Hispanic all races = 13%, Black non-Hispanic = 37%, White non-Hispanic = 37%, and multiracial/other race non-Hispanic = 13%. Characteristics of children recruited from each study site are presented in Appendix Table 1. Questionnaire responses are summarized in Table 2.

Retention was 80% at age 2.5 (*n* = 1,062) and 74% at age 4 (*n* = 985). Families with children enrolled in Medicaid, who were Black, and with younger PCGs were more likely to drop out. At age 2.5 y, 7% of children had cavitated-level caries experience (d3mfs >0). This increased to 29% by age 4, with significant ($P \leq 0.001$) disparities by race/ethnicity (i.e., compared to non-Hispanic Whites = 14%, non-Hispanic Blacks = 39% [odds ratio (OR) = 3.4], Hispanics of all races = 38% [OR = 3.3], and non-Hispanic multirace/other race = 32% [OR = 2.7]). There were also significant differences ($P \leq 0.001$) by Medicaid status (non-Medicaid = 15% vs. Medicaid = 38%; OR = 3.1) but not ($P = 0.07$) by sex (females = 26% vs. males = 31%; OR = 1.3).

Significant ($P < 0.001$) variables included in the final multivariable prediction model (AUC = 0.73, Appendix Fig. 1; bootstrap estimate, internal calibration; AUC = 0.68) are shown in Table 3. Model calibration between observed and predicted caries experience was excellent (intraclass correlation coefficient [ICC] = 0.95). Coefficients from the regression model were used to determine the number of points each response contributed to the CRA score (range from 0–11). The distribution of scores, percentage with observed caries for each score, and diagnostic test statistics are shown in Table 4.

Additional analyses were performed to explore the relevance of the final model risk score when applied to secondary outcomes, different ages, or population subgroups (Table 5; Appendix Table 2). Separate risk models with distinct scoring algorithms were also created for each of the above situations, resulting in similar, albeit slightly higher, AUCs than when using the primary model risk score (Table 5). These data suggest that population/age subset-specific and outcome-specific models are not necessary, which will aid with implementation.

Discussion

There are few high-quality, longitudinal caries prediction studies on preschool children (Jørgensen and Twetman 2020), few in US cohorts (Fontana et al. 2011), and insufficient evidence to support routine screening by primary care clinicians for dental caries (USPSTF 2021). To address these concerns and aid

Table 2. Questionnaire Responses at Child Ages 1, 2.5, and 4 Years.

Questionnaire Item	Response	Baseline (Age 1) (*n* = 1,326)	Age 2.5 y (*n* = 1,062)	Age 4 y (*n* = 985)
Does your child have any teeth?	No	7 (6–9)		
	Yes	93 (91–94)		
Does your child have any cavities or fillings?	No	82 (80–85)	82 (80–84)	77 (74–79)
	Yes	1 (1–2)	5 (4–6)	15 (13–17)
	Don't know	16 (14–18)	13 (11–15)	8 (6–10)
Did your child's doctor or dentist prescribe fluoride drops or tablets?	No	95 (94–97)	94 (93–96)	93 (92–94)
	Yes	1 (1–2)	3 (2–4)	5 (3–6)
	Don't know	3 (2–4)	3 (2–4)	2 (1–3)
Does your child wear any oral appliances such as space maintainers?	No	100 (99–100)	100 (100–100)	99 (99–100)
	Yes	0 (0–0)	0 (0–0)	0 (0–1)
	Don't know	0 (0–1)	0 (0–0)	0 (0–0)
Does your child receive topical fluoride from a health professional (doctor, dentist, nurse, hygienist, etc.)?	No	87 (85–89)	61 (58–63)	45 (42–48)
	Yes	12 (10–14)	37 (35–40)	53 (50–55)
	Don't know	1 (0–2)	2 (1–3)	2 (1–3)
How often does an adult brush your child's teeth?	Daily	58 (55–60)	92 (91–94)	91 (90–93)
	Weekly	16 (14–18)	6 (5–8)	7 (6–8)
	Monthly	2 (1–3)	1 (0–1)	1 (0–1)
	Never	25 (22–27)	1 (0–1)	1 (0–2)
How often are your child's teeth brushed with toothpaste?	Daily	33 (30–35)	88 (86–90)	95 (93–96)
	Weekly	10 (8–12)	6 (5–8)	3 (2–4)
	Monthly	1 (0–2)	1 (0–1)	0 (0–1)
	Never	56 (53–59)	5 (4–6)	2 (1–2)
How often are your child's teeth brushed with nonfluoride toothpaste?	Daily	23 (21–26)	40 (37–43)	32 (29–34)
	Weekly	8 (6–9)	5 (4–6)	3 (2–4)
	Monthly	1 (1–2)	1 (1–2)	2 (1–2)
	Never	68 (65–70)	54 (51–57)	64 (61–66)
How often does your child share a toothbrush with another person?	Daily	1 (0–1)	2 (1–3)	1 (0–2)
	Weekly	2 (1–2)	2 (2–3)	2 (1–3)
	Monthly	0 (0–1)	2 (1–3)	1 (1–2)
	Never	97 (96–98)	94 (93–95)	95 (94–97)
How often do you check your child's teeth for anything unusual?	Daily	43 (40–46)	45 (42–48)	44 (41–48)
	Weekly	34 (31–37)	33 (30–36)	32 (29–35)
	Monthly	7 (6–9)	14 (12–16)	16 (14–19)
	Never	15 (13–17)	9 (7–10)	8 (6–9)
When brushing, how often do your child's gums bleed?	Daily	1 (1–2)	1 (0–1)	1 (0–1)
	Weekly	1 (0–1)	2 (1–2)	1 (1–2)
	Monthly	0 (0–1)	2 (1–3)	1 (1–2)
	Never	98 (97–99)	96 (95–97)	97 (96–98)
How often do you clean inside your child's mouth and/or gums?	Daily	57 (54–59)	73 (70–75)	67 (64–70)
	Weekly	18 (15–20)	12 (10–14)	15 (13–17)
	Monthly	4 (3–5)	2 (1–2)	3 (2–4)
	Never	22 (20–24)	14 (12–16)	15 (13–17)
Does your child usually (throughout the day) drink from a bottle or sippy cup?	No	5 (4–6)	35 (32–38)	79 (76–81)
	Yes	95 (94–96)	65 (62–68)	21 (19–24)
How often does your child go to sleep while nursing or while drinking something other than water from a bottle/sippy cup?	Daily	47 (44–49)	14 (12–16)	3 (2–4)
	Weekly	11 (10–13)	6 (5–8)	1 (1–2)
	Monthly	2 (1–3)	2 (1–2)	1 (0–1)
	Never	40 (37–43)	78 (76–81)	94 (93–96)
How often does your child eat or drink anything other than plain water before going to bed (and after you have brushed his/her teeth, if teeth are brushed)?	Daily	63 (60–66)	27 (25–30)	18 (15–20)
	Weekly	13 (11–15)	19 (17–21)	19 (16–21)
	Monthly	2 (1–3)	6 (5–7)	8 (6–10)
	Never	22 (20–24)	48 (45–51)	56 (53–59)
How often does your child typically drink tap water, including filtered water from the refrigerator?	Daily	58 (55–60)	74 (72–77)	75 (72–77)
	Weekly	13 (11–15)	9 (8–11)	8 (6–10)
	Monthly	3 (2–4)	2 (1–3)	2 (1–2)
	Never	27 (24–29)	14 (12–17)	16 (14–18)
How often do you give your child sugary snacks such as raisins, candy, cookies, cakes, or cereal between meals?	Three or more times a day	4 (3–5)	4 (3–5)	4 (3–6)
	One or 2 times a day	41 (38–44)	58 (55–61)	55 (52–58)
	Weekly	25 (23–27)	32 (29–35)	35 (32–38)
	Monthly	7 (6–8)	5 (4–6)	4 (3–5)
	Never	23 (21–26)	1 (1–2)	2 (1–2)

(continued)

Table 2. (continued)

Questionnaire Item	Response	Baseline (Age 1) (*n* = 1,326)	Age 2.5 y (*n* = 1,062)	Age 4 y (*n* = 985)
How often do you give your child sugary drinks such as regular soda, sweet tea, chocolate milk, strawberry milk, or fruit juice between meals?	Three or more times a day	4 (3–5)	8 (6–9)	6 (4–7)
	One or 2 times a day	26 (23–28)	43 (40–46)	44 (41–47)
	Weekly	18 (16–20)	24 (22–27)	29 (26–32)
	Monthly	5 (4–7)	10 (9–12)	11 (10–13)
	Never	47 (45–50)	15 (13–17)	10 (8–12)
How often do you clean your child's pacifier with juice, soda, honey, or sweet drink?	Daily	1 (1–2)	0 (0–1)	0 (0–1)
	Weekly	2 (1–3)	1 (0–1)	0 (0–0)
	Monthly	1 (1–2)	0 (0–0)	0 (0–0)
	Never	53 (50–56)	34 (31–36)	31 (28–34)
	Don't use pacifier	42 (40–45)	65 (62–68)	69 (66–72)
How often do you clean your child's pacifier by putting it in your mouth?	Daily	14 (12–16)	2 (1–3)	0 (0–1)
	Weekly	6 (4–7)	1 (0–1)	0 (0–1)
	Monthly	2 (1–3)	1 (0–1)	0 (0–0)
	Never	34 (31–37)	28 (25–31)	27 (25–30)
	Don't use pacifier	45 (42–47)	69 (66–72)	72 (69–74)
How often do you share/taste food with your child using the same spoon, fork, glass, or other utensil?	Daily	46 (43–48)	26 (23–29)	14 (12–17)
	Weekly	22 (20–25)	31 (28–34)	28 (25–31)
	Monthly	4 (3–5)	7 (6–9)	10 (8–12)
	Never	28 (26–31)	35 (33–38)	47 (44–51)
How often do you kiss your child on the mouth?	Daily	61 (58–63)	57 (54–60)	50 (46–53)
	Weekly	12 (10–14)	15 (13–17)	12 (10–13)
	Monthly	3 (2–4)	3 (2–4)	5 (3–6)
	Never	25 (22–27)	25 (22–27)	34 (31–37)
How often do you take your child to the dentist?	Never	85 (83–87)	34 (31–36)	16 (14–18)
	Only when in pain	0 (0–1)	1 (0–1)	1 (0–1)
	Yearly	6 (5–7)	19 (17–22)	20 (18–23)
	Twice yearly	8 (7–9)	46 (43–49)	63 (60–66)
Is it very difficult to get your child to the doctor or the dentist?	No	97 (96–98)	93 (91–94)	94 (92–95)
	Yes	3 (2–4)	7 (6–9)	6 (5–8)
Is your child covered by additional health insurance?	No	54 (51–57)	54 (51–57)	50 (47–53)
	Yes	45 (42–48)	45 (42–47)	49 (46–52)
	Don't know	1 (0–2)	1 (1–2)	1 (0–1)
Is your child covered by additional dental insurance?	No	63 (61–66)	58 (56–61)	53 (51–56)
	Yes	33 (30–35)	39 (36–42)	45 (42–47)
	Don't know	4 (3–5)	2 (2–3)	2 (1–3)
Does your child participate in public assistance programs?	No	40 (37–43)	51 (48–54)	59 (56–61)
	Yes	60 (57–62)	48 (46–51)	41 (38–44)
	Don't know	0 (0–1)	0 (0–1)	0 (0–1)
Do you have any natural teeth?	No	1 (1–2)	1 (1–2)	1 (1–2)
	Yes	99 (98–99)	99 (98–99)	99 (98–99)
Have you had cavities, fillings and/or teeth pulled in the last 2 years?	No	46 (43–48)	50 (47–53)	48 (45–51)
	Yes	54 (52–57)	50 (47–53)	52 (49–55)
How often do your gums bleed when you brush?	Daily	9 (8–11)	8 (6–9)	8 (6–9)
	Weekly	13 (11–15)	14 (12–16)	12 (10–14)
	Monthly	23 (21–25)	18 (16–21)	21 (19–24)
	Never	55 (52–58)	60 (57–63)	59 (56–62)
How often do you brush your teeth?	Daily	98 (97–99)	98 (98–99)	98 (98–99)
	Weekly	2 (1–2)	1 (1–2)	1 (1–2)
	Monthly	0 (0–1)	0 (0–0)	0 (0–0)
	Never	0 (0–1)	0 (0–1)	0 (0–0)
How often do you use toothpaste when you brush?	Daily	98 (98–99)	99 (98–99)	98 (97–99)
	Weekly	1 (0–2)	1 (0–2)	1 (1–2)
	Monthly	1 (0–1)	0 (0–0)	0 (0–0)
	Never	0 (0–0)	0 (0–1)	0 (0–1)
How often do you eat sugary snacks such as raisins, candy, cookies, cakes, or cereal bars between meals?	Three or more times a day	14 (12–16)	13 (11–14)	10 (8–12)
	One or 2 times a day	46 (43–49)	46 (43–49)	44 (41–47)
	Weekly	31 (29–34)	33 (30–36)	35 (32–38)
	Monthly	7 (5–8)	6 (5–8)	8 (7–10)
	Never	2 (2–3)	2 (2–3)	3 (2–4)

(continued)

Table 2. (continued)

Questionnaire Item	Response	Baseline (Age 1) (*n* = 1,326)	Age 2.5 y (*n* = 1,062)	Age 4 y (*n* = 985)
How often do you drink sugary drinks such as regular soda, sweet tea, chocolate milk, strawberry milk, sports drinks, or fruit juice between meals?	Three or more times a day	22 (20–24)	17 (15–19)	14 (12–16)
	One or 2 times a day	38 (36–41)	39 (36–42)	39 (36–42)
	Weekly	21 (19–24)	22 (20–25)	22 (20–25)
	Monthly	9 (7–10)	11 (9–13)	12 (10–14)
	Never	10 (8–11)	11 (10–13)	13 (11–15)
How often do you eat or drink anything other than plain water before going to bed (and after brushing your teeth, if teeth are brushed)?	Daily	39 (36–41)	32 (29–34)	28 (26–31)
	Weekly	17 (15–19)	18 (16–20)	18 (15–20)
	Monthly	7 (5–8)	6 (4–7)	7 (6–8)
	Never	38 (35–40)	45 (42–48)	47 (44–50)
How often do you see your health care provider for regular checkups?	Two times each year	34 (31–36)	33 (30–35)	31 (28–33)
	Yearly	51 (48–53)	54 (51–57)	56 (53–59)
	Every other year	8 (7–10)	8 (6–10)	9 (8–11)
	Never	7 (6–8)	5 (4–6)	4 (3–5)
How often do you get dental checkups?	Two times each year	44 (41–46)	48 (45–51)	53 (50–57)
	Yearly	27 (25–30)	32 (29–35)	27 (24–30)
	Every other year	17 (15–19)	12 (10–13)	11 (9–13)
	Never	12 (10–14)	9 (7–10)	8 (7–10)
Do you have health insurance?	No	17 (15–19)	11 (9–13)	9 (7–11)
	Yes	83 (81–85)	89 (87–91)	91 (89–93)
Do you have dental insurance?	No	30 (27–32)	25 (23–28)	21 (19–24)
	Yes	70 (68–73)	75 (72–77)	79 (76–81)
Do you primarily speak a language other than English at home?	No	81 (79–83)	81 (79–83)	81 (79–83)
	Yes	19 (17–21)	19 (17–21)	19 (17–21)
Is an adult in the child's household employed?	No	18 (16–20)	14 (12–16)	12 (10–14)
	Yes	82 (80–84)	86 (84–88)	88 (86–90)
Which of the following categories best represents the combined income of all family members in your household for the past 12 months?	Less than $5,000	15 (13–17)	13 (11–15)	11 (9–13)
	$5,000–$9,999	8 (7–9)	6 (5–7)	6 (5–8)
	$10,000–$19,999	9 (7–11)	13 (11–15)	11 (9–13)
	$20,000–$29,999	11 (9–13)	11 (9–13)	10 (8–12)
	$30,000–$39,999	6 (5–7)	8 (6–9)	10 (8–11)
	$40,000–$49,999	6 (5–7)	4 (3–5)	6 (5–7)
	$50,000–$79,999	13 (11–15)	14 (12–16)	15 (13–17)
	$80,000–$99,999	7 (6–8)	7 (6–9)	8 (6–9)
	$100,000 or more	12 (11–14)	14 (12–16)	18 (16–20)
	Don't know	12 (10–14)	9 (7–10)	6 (5–7)
I do a/an ___ job taking care of the child's teeth and/or gums (past behavior)	Excellent	22 (20–24)	21 (18–23)	25 (22–28)
	Very good	30 (28–33)	41 (38–44)	42 (39–45)
	Good	33 (31–36)	31 (28–34)	27 (24–29)
	Fair	11 (10–13)	7 (6–9)	7 (5–8)
	Poor	3 (2–4)	0 (0–1)	0 (0–0)
I do a/an ___job taking care of the child's medical health (past behavior)	Excellent	68 (65–70)	61 (58–63)	56 (53–59)
	Very good	26 (24–29)	34 (31–37)	37 (34–40)
	Good	5 (4–7)	5 (4–7)	7 (5–8)
	Fair	0 (0–1)	0 (0–0)	0 (0–1)
	Poor			0 (0–0)
Number of children who live with you, mean (95% CI)		2.10 (2.03–2.17)	2.22 (2.15–2.29)	2.43 (2.36–2.51)
Number of adults who live with you, mean (95% CI)		1.91 (1.87–1.94)	1.87 (1.83–1.91)	1.81 (1.77–1.85)

Responses are percentage (95% CI) unless otherwise indicated.
CI, confidence interval.

with future implementation, a quick and objective 10-item parent-completed questionnaire was developed for use in medical settings. The tool had good accuracy (AUC = 0.73), excellent calibration, and good internal validity for identifying children at increased risk for cavitated lesions.

Caries risk in young children can be assessed using variables easily available at periodic dental/medical examinations (Zero et al. 2001), but most CRA tools are long and require assessment by trained staff, making them inefficient and time-consuming for use in the quick-paced medical setting. Although caries experience and a dental clinician's subjective impression of risk have been identified as important caries predictors, these are not helpful to use in infants (with few teeth and recent eruption) in a primary health care setting where most

Table 3. Multivariable Model Predicting Having Cavitated Caries Experience by Age 4.

10 Questions Asked at Baseline (Age 1) Included in Final Model	Response	Odds Ratio (95% CI)	Risk Score Points Based on Model Coefficients
Primary Multivariable Model by Age 4[a]			
10 Questions Asked at Baseline (Age 1) Included in Final Model (Including Race and Ethnicity in the Model)[a]	Response	Odds Ratio (95% CI)	Risk Score Points Based on Model Coefficients
Child			
How often do you give your child sugary snacks such as raisins, candy, cookies, cakes, or cereal between meals?	3× or more/d	2.22 (1.17–4.22)	2
	1–2×/d or weekly	1.55 (1.15–2.09)	1
How often do you clean your child's pacifier with juice, soda, honey, or sweet drink?	Daily, weekly, monthly	2.17 (1.26–3.72)	2
How often do you share/taste food with your child using the same spoon, fork, glass, or other utensil?	Daily	1.32 (0.84–2.07)	1
	Never	1.43 (1.07–1.91)	1
Was your child born more than 3 weeks (premature) before the expected delivery date?	Yes	1.48 (1.19–1.85)	1
Was your child delivered by C-section?	No (born vaginally)	1.28 (1.07–1.54)	1
Is your child covered by Medicaid or state insurance?	Yes	1.74 (1.25–2.43)	1
Do you consider your child to be Spanish, Hispanic, or Latino? What is your child's racial background?	Non-Hispanic Black	1.80 (1.22–2.65)	1
	Hispanic	1.90 (1.36–2.67)	1
	Non-Hispanic Multirace/other	1.96 (1.09–3.51)	1
Primary Caregiver			
How often do you brush your teeth?	Not daily	2.72 (1.70–4.35)	2
How often do your gums bleed when you brush?	Daily	1.83 (1.31–2.79)	1
	No teeth	1.66 (0.59–4.66)	1
Have you had cavities, fillings, and/or teeth pulled in the last 2 years?	Yes	1.55 (1.28–1.87)	1
Modified Primary Model[b]			
10 Questions Asked at Baseline (Age 1) Included in Final Model (Excluding Race and Ethnicity in the Model)[b]	Response	Odds Ratio (95% CI)	Risk Score Points Based on Model Coefficients
Child			
How often do you give your child sugary snacks such as raisins, candy, cookies, cakes, or cereal between meals?	3× or more/d	2.26 (1.18–4.33)	2
	1–2×/d or weekly	1.60 (1.18–2.16)	1
How often do you clean your child's pacifier with juice, soda, honey, or sweet drink?	Daily, weekly, monthly	2.32 (1.35–4.00)	2
How often do you share/taste food with your child using the same spoon, fork, glass, or other utensil?	Daily	1.40 (0.90–2.16)	1
	Never	1.48 (1.12–1.96)	1
Was your child born more than 3 weeks (premature) before the expected delivery date?	Yes	1.50 (1.21–1.85)	1
Was your child delivered by C-section?	No (born vaginally)	1.30 (1.09–1.56)	1
Is your child covered by Medicaid or state insurance?	Yes	2.24 (1.48–3.37)	2
Primary caregiver			
How often do you brush your teeth?	Not daily	2.67 (1.69–4.23)	2
How often do your gums bleed when you brush?	Daily	1.93 (1.43–2.61)	1
	No teeth	1.68 (0.90–3.12)	1
Have you had cavities, fillings, and/or teeth pulled in the last 2 years?	Yes	1.60 (1.35–1.90)	1
Primary language spoken at home	Not English	1.41 (1.12–1.79)	1

CI, confidence interval; ROC, receiver operating characteristic.
[a]Area under the ROC curve = 0.73 for model; area under ROC curve for risk score bootstrap estimate = 0.68.
[b]If race and ethnicity are forced out of the model, they are replaced in the logistic regression by the question about primary language spoken at home. Area under the ROC curve = 0.71 for this modified model.

non–dental health professionals have received little or no training in dental health and caries detection.

The predictive accuracy of the parent-administered screening model in this study is like that based on more complex, expensive analyses of oral microbiome samples (AUC = 0.71; Grier et al. 2021) and interviewer-administered caries risk questionnaires developed in other countries for medical settings (AUC = 0.71−0.75 for development of ICDAS ≥3 for 2- to 3-y-olds; Kalhan et al. 2020). It is also like a recent study that used US health record information from well-child visits starting at age 18 mo (later than our study) to develop a CRA tool for young children (AUC = 0.67; Nowak et al. 2020). In the Nowak study, 3 factors predicted high caries risk: prolonged breastfeeding, preferred language not English, and no-show pediatric visit rates >20%. However, information on other modifiable risk factors important to guide prevention was not available, and the outcome variable of high/low caries risk was established based on a subjective analysis of risk factors

Table 4. Distribution of Primary Risk Model Scores and Accuracy to Identify Children with Cavitated-Level Caries Experience by Age 4 y.

Score	Score Distribution, %	Caries, %	No Caries, %	Sensitivity, %	Specificity, %	Positive Likelihood Ratio	Negative Likelihood Ratio	Positive Predictive Value, %	Negative Predictive Value, %
0	1	9	91	100	0	1.0		29	
1	5	6	94	100	1	1.0		29	91
2	11	10	90	99	7	1.1	0.18	30	93
3[a]	18	13	87	95	21	1.2	0.24	33	91
4	19	24	76	87	42	1.5	0.31	38	89
5[b]	20	38	62	71	62	1.9	0.46	43	84
6	17	41	59	45	80	2.2	0.69	48	78
7	8	54	46	21	94	3.4	0.84	58	75
8	2	61	39	7	99	5.3	0.94	68	72
9	1	75	25	3	100	14.9	0.98	84	72
10	<1	100	0	1	100		0.99	100	71
11	<1	100	0	0	100		1.00	100	71

[a]Example score chosen to provide high sensitivity and low specificity (e.g., resulting in only 5% false negatives [children who will develop cavitated lesions who would not be treated and/or referred] and about 80% false positives [children who will not develop caries lesions being treated and/or referred]).
[b]Example score chosen to provide both modest sensitivity and specificity (e.g., resulting in approximately 30% false negatives and approximately 40% false positives).
Based on the distribution of both of these scores in the population, both would decrease or prioritize, with varying accuracy, the number of children treated (e.g., with fluoride varnish in the medical setting) and/or referred compared to the "universal" recommendations supported by current policies. The percentage of children treated/referred as higher risk would be 48% using a score of 5 as the cutoff threshold for risk and 85% for a score of 3. The choice of score threshold to use would depend on how the tool is being used in practice.

Table 5. Area under ROC Curve for Different Outcomes/Ages/Groups Using Either the Scores Derived from the Primary Risk Model or Using Scores from Specific Risk Models.

Prediction Model Primary Outcome	Area under the ROC Curve for Different Outcomes/Ages/Groups When Using the Primary Risk Model Scores[a]	Area under the ROC Curve for Different Outcomes/Ages/Groups When Using Risk Model Specific Scores to Each Outcome/Age/Group[b]
Predict d3mfs >0 (cavitated caries experience) at age 4 using age 1 responses, all participants (primary outcome risk score)	0.68	
Predict d1mfs >0 (cavitated and noncavitated caries experience) at age 4 using age 1 responses, all participants	0.63	0.63
Predict d5mfs >0 (extensive cavitated caries experience only) at age 4 using age 1 responses, all subjects	0.68	0.73
Predict d3mfs >0 (cavitated caries experience) at age 2.5 using age 1 responses, all subjects	0.70	0.75
Predict d3mfs >0 (cavitated caries experience) at age 4 using age 2.5 questionnaire responses	0.66	0.71
Predict d3mfs >0 (cavitated lesions) at age 4 using age 1 responses, including only participants enrolled in Medicaid	0.59	0.66
Predict d3mfs >0 (cavitated caries experience) at age 4 using age 1 responses, including only participants not enrolled in Medicaid	0.60	0.68

d1mfs, decayed, missing and filled surfaces; d = ICDAS ≥ 1; d3mfs, decayed, missing, and filled surfaces; d = ICDAS ≥ 3; d5mfs, decayed, missing and filled surfaces; d = ICDAS ≥ 5; ROC, receiver operating characteristic.
[a]The "primary" risk score used baseline data (age 1 questionnaire responses) from all subjects to predict d3mfs>0 (cavitated caries experience) at age 4. The data presented are after internal validation (bootstrapping). That same scoring algorithm was then used to predict other caries outcomes/ages (e.g., applied to the questionnaire responses at the 2.5-y-old visit, etc.) and was evaluated for subgroups of subjects (e.g., Medicaid enrolled and non-Medicaid enrolled). The intent was to understand how implementation of a single scoring risk algorithm would perform versus requiring different scoring algorithms for different outcomes/ages/groups.
[b]In addition, separate risk models with distinct scoring algorithms were also created for each of the above situations to use as comparisons.

and any caries lesion or enamel "irregularity," without information on caries criteria used or examiner calibration, making comparisons difficult. To increase accuracy of prediction within the present tool, addition of clinical/microbial variables may be necessary (Kalhan et al. 2020) but will have to be evaluated versus the impact on cost and training.

Because of the multifactorial and chronic nature of the caries disease process, studies on CRA are complex, with multiple factors influencing risk at the individual, family, and community levels, affected by sociodemographic factors (Fontana et al. 2019). Two sociodemographic items were part of the final primary tool, which is not surprising given the increased caries experience in minority and poor children (Dye et al. 2015). These variables are likely serving as proxies for the impact of other socioeconomic factors on health (Madhussodanan 2021) and highlight the challenge between the need for improved accuracy versus awareness of discrimination biases that may result from their inclusion. When race/ethnicity was forced out of the final model, it was replaced by language spoken at home other than English and did not greatly affect the accuracy of the model.

Like other studies, the final prediction model involves child and PCG risk factors (Kalhan et al. 2020). Several birth cohort studies have concluded that parents' poor oral health is a significant risk factor for children's caries experience, likely because it reflects the intricacies of shared genetic/environmental factors that contribute to an individual's oral health (Hariyani et al 2020), thus underscoring the importance of supporting parents' health. Maternal oral health, parental deprivation, and maternal weight, intake of sugar, and fat in pregnancy have also been associated and/or found to be strong predictors of caries in children (Dye et al. 2011).

Mode of birth and timing of delivery, 2 risk factors in our model, have also been associated with caries risk. In agreement with this study, compared to children delivered by caesarean section, vaginally born Thai (Pattanaporn et al. 2013) and Brazilian children (Ladeira et al. 2021) experienced higher caries prevalence. Caesarean section may have an impact on caries development by affecting the oral microbiome composition and resulting immune and inflammatory responses (Li et al. 2018). Socioeconomic factors may also affect the strength of the relationship, as low-risk caesarean births are higher among highly educated women in some parts of the world (Boerma et al. 2018), and higher socioeconomic status is associated with lower caries rates (Dye et al. 2015). In contrast, data from a birth cohort study in Sweden, with fewer preterm births and lower caries rates compared to other studies, found that 5-y-olds delivered by caesarean section had a significantly elevated risk of caries (Boustedt et al. 2018). Regarding preterm birth, a recent meta-analysis concluded, as in this study, that it increased the risk of caries in young children (Shi et al. 2020). This may be explained, at least in part, because maternal health habits such as smoking, drinking, and malnutrition affect the development of the primary dentition and impede immunological responses (Tanaka et al. 2009). Resulting structural defects of the tooth can accumulate oral biofilms and make oral hygiene difficult, leading to more caries (Costa et al. 2017). In contrast, preterm infants will experience closer follow-up, and thus parents may be exposed to more health education opportunities, which could mitigate the negative impact on oral health.

Some of the included risk factors in the 10-item model, such as eating habits, are modifiable and may have broader impacts on general health. The role of diet is so prominent in caries etiology that current guidelines call for limiting free sugars intake to less than 10% of total energy intake to minimize the risk of dental caries throughout life (Moynihan and Kelly 2014), among other individual and public health approaches.

Once a caries prediction tool is developed, significant challenges remain around its implementation, with barriers associated with training of the medical workforce, time constraints, and difficulties of referrals (Dickson-Swift et al. 2020). Implementation will require that risk be displayed in a user-friendly interface that fits seamlessly into the clinical workflow to facilitate decision-making (Fontana et al. 2020). Scoring systems, such as the one developed in this study, are popular as they are practical and allow a rapid assessment with or without the need for electronic devices.

Implementation will also require assessing the acceptability and economic impact of establishing a risk-based approach to caries screening prevention. Even though there is a paucity of economic evaluations regarding caries prediction models (Fransson et al. 2021), studies have shown risk-based prevention can be cost-effective in young children (Holst et al. 1997). In addition, while the USPSTF (2021) recommends fluoride varnish (FV) for all children regardless of risk, and studies suggest that most pediatricians support providing oral health activities, fewer report engaging in these activities with all patients (Quiñonez et al. 2014). Limited data also suggest fluoride is being recommended in some medical settings based on perceived risk (Fontana et al. 2018). A risk-based approach for FV use would be in line with recommendations from dental organizations, as studies suggest FV is not cost-effective when applied to low caries risk populations (Schwendicke et al. 2018). High-risk individuals require recurrent preventive services (Weyant et al. 2013) that may be difficult to achieve in a single type of setting, and thus working in an interprofessional manner might be the only way to address the access to care needed for effectiveness of interventions delivered (Graif et al. 2021).

Limitations of this study include use of a convenience sample, missing data over time (imputed during analyses), and need for external validation and cost-effectiveness of a risk-based strategy using this model (preliminary data have found use of this model cost-effective in delivering preventive care; Doan et al. 2021). Use in low-risk populations is likely to result in lower accuracy. The definition of PCG may have introduced some bias. Yet, as this tool was developed to be used in primary health care settings, it is likely that the adult present would be able to meet the criteria used in this study. To aid with implementation, the risk tool was limited to 10 items and did not include data that would require further training/costs (e.g., clinical, salivary, microbial, and genetic biomarkers). Behavioral research will need to determine how to better translate risk predictions into effective messaging-communication to facilitate sustained behavior change and improved caries outcomes (French et al. 2017; Fontana et al. 2020). This caries risk model was generated based on population-level risk across a varying background of preventive care, closely representing real-world implementation in practice. A specific child's risk may be influenced by the type and level of preventive care received. The primary health care networks from which children were recruited are in communities that have water fluoridation. This does not necessarily mean the child was exposed to water fluoridation at home but strongly suggests they likely live in a fluoridated community. Strengths of this study include a diverse sample of children followed from 1 to 4 y of age, with detailed questionnaires completed by parents and dental exams conducted by calibrated examiners.

In conclusion, a self-administered 10-item caries prediction model for use in medical settings at age 1 shows good agreement with cavitated-level caries experience by age 4. Although all children should have access to dental care and preventive services, this screening tool can help primary care clinicians prioritize children in resource-limited settings.

Author Contributions

M. Fontana, contributed to conception and design, data interpretation, drafted and critically revised the manuscript; G.J. Eckert, contributed to design, data analysis and interpretation, drafted and critically revised the manuscript; B.P. Katz, P. McKnight, contributed to design, data analysis and interpretation, critically revised the manuscript; M.A. Keels, B.T. Levy, S.M. Levy, A.R. Kemper, J. Warren, contributed to design, data interpretation, critically revised the manuscript; E. Yanca, R. Jackson, J.L. Kolker, J.M. Daly, S. Kelly, J. Talbert, contributed to data acquisition and interpretation, critically revised the manuscript. All authors gave final approval and agree to be accountable for all aspects of the work.

Acknowledgments

The team thanks Beth Patterson, Freddi Gallack, Parul Patel, and Brenda Pattison.

Declaration of Conflicting Interests

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The authors disclosed receipt of the following financial support for the research, authorship, and/or publication of this article: This study was supported by National Institutes of Health NIH-U01 DE021412 and NIH CTSA grants: UL1-TR000442 (University of Iowa), 2UL1TR000433 (University of Michigan), and UL1-TR000006 (Indiana University).

ORCID iDs

M. Fontana https://orcid.org/0000-0003-2357-7534
G.J. Eckert https://orcid.org/0000-0001-7798-7155

References

American Academy of Pediatrics (AAP) Section of Pediatric Dentistry and Oral Health. 2008. Policy statement: preventive oral health intervention for pediatricians. Pediatrics. 122(6):1387–1394.

Boerma T, Ronsmans C, Melesse DY, Barros AJD, Barros FC, Juan L, Moller AB, Say L, Hosseinpoor AR, Yi M, et al. 2018. Global epidemiology of use of and disparities in caesarean sections. Lancet. 392(10155):1341–1348.

Boustedt K, Roswall J, Twetman S, Dahlgren J. 2018. Influence of mode of delivery, family and nursing determinants on early childhood caries development: a prospective cohort study. Acta Odontol Scand. 76(8):595–599.

Burgette JM, Divaris K, Fontana M. 2021. Reducing inequities in early childhood dental caries in primary health care settings. JAMA Health Forum. 2(12):e214115.

Cagetti MG, Bontà G, Cocco F, Lingstrom P, Strohmenger L, Campus G. 2018. Are standardized caries risk assessment models effective in assessing actual caries status and future caries increment? A systematic review. BMC Oral Health. 18(1):123.

Costa FS, Silveira ER, Pinto GS, Nascimento GG, Thomson WM, Demarco FF. 2017. Developmental defects of enamel and dental caries in the primary dentition: a systematic review and meta-analysis. J Dent. 60:1–7.

Dickson-Swift V, Kenny A, Gussy M, McCarthy C, Bracksley-O'Grady S. 2020. The knowledge and practice of pediatricians in children's oral health: a scoping review. BMC Oral Health. 20(1):211.

Doan T, Janusz CB, Rose A, Gebremariam A, Fontana M, Keels MA, Eckert G, Levy S, Hara A, Prosser L. 2021. Simulated health outcomes of dental caries prevention in US children. J Dent Res. 100(Special Issue A):#2253.

Dye BA, Thornton-Evans G, Li X, Iafolla TJ. 2015. Dental caries and sealant prevalence in children and adolescents in the United States, 2011-2012. NCHS Data Brief, No. 191:1–8. Hyattsville (MD): National Center for Health Statistics.

Dye BA, Vargas CM, Lee JJ, Magder L, Tinanoff N. 2011. Assessing the relationship between children's oral health status and that of their mothers. J Am Dent Assoc. 142(2):173–183.

Fontana M, Carrasco Labra A, Spallek H, Eckert G, Katz B. 2020. Improving caries risk prediction modeling: a call for action. J Dent Res. 99(11):1215–1220.

Fontana M, Eckert GJ, Keels MA, Jackson R, Katz BP, Kemper AR, Levy BT, Levy SM, Yanca E, Kelly S, et al. 2019. Predicting caries in medical settings-risk factors in diverse infant groups. J Dent Res. 98(1):68–76.

Fontana M, Eckert GJ, Keels MA, Jackson R, Katz B, Levy BT, Levy SM. 2018. Fluoride use in healthcare settings: association with children's caries risk. Adv Dent Res. 29(1) 24–34.

Fontana M, Jackson R, Eckert G, Swigonski N, Chin J, Zandona AF, Ando M, Stookey GK, Downs S, Zero DT. 2011. Identification of caries risk factors in toddlers. J Dent Res. 90(2):209–214.

Fransson H, Davidson T, Rohlin M; Foresight Research Consortium, Christell H. 2021. There is a paucity of economic evaluations of prediction methods of caries and periodontitis: a systematic review. Clin Exp Dent Res. 7(3):385–398.

French DP, Cameron E, Benton JS, Deaton C, Harvie M. 2017. Can communicating personalised disease risk promote healthy behaviour change? A systematic review of systematic reviews. Ann Behav Med. 51(5):718–729.

Graif C, Meurer J, Fontana M. 2021. An ecological model to frame delivery of pediatric preventive care. Pediatrics. 148(Suppl 1):s13–s20.

Grier A, Myers JA, O'Connor TG, Quivey RG, Gill SR, Kopycka-Kedzierawski DT. 2021. Oral microbiota composition predicts early childhood caries onset. J Dent Res. 100(6):599–607.

Hariyani N, Do LG, Spencer AJ, Thomson WM, Scott JA, Ha DH. 2020. Maternal caries experience influences offspring's early childhood caries: a birth cohort study. Community Dent Oral Epidemiol. 48(6):561–569.

Holst A, Mårtensson I, Laurin M. 1997. Identification of caries risk children and prevention of caries in pre-school children. Swed Dent J. 21(5):185–191.

International Caries Detection and Assessment System (ICDAS). 2020. ICCMS. [accessed 2021 July 1]. https://www.iccms-web.com/content/icdas.

Jørgensen MR, Twetman S. 2020. A systematic review of risk assessment tools for early childhood caries: is there evidence? Eur Arch Paediatr Dent. 21(2):179–184.

Kalhan TA, Un Lam C, Karunakaran B, Chay PL, Chng CK, Nair R, Lee YS, Fong MCF, Chong YS, Kwek K, et al. 2020. Caries risk prediction models in a medical health care setting. J Dent Res. 99(7):787–796.

Kassebaum NJ, Bernabe E, Dahiya M, Bhandari B, Murray CJ, Marcenes W. 2015. Global burden of untreated caries: a systematic review and meta regression. J Dent Res. 94(5):650–658.

Ladeira LLC, Martins SP, Costa CM, Costa EL, da Silva RA, Fraiz FC, Ribeiro CCC. 2021. Caesarean delivery and early childhood caries: estimation with marginal structural models in Brazilian pre-schoolers. Community Dent Oral Epidemiol. 49(6):602–608.

Li H, Wang J, Wu L, Luo J, Liang X, Xiao B, Zhu Y. 2018. The impacts of delivery mode on infant's oral microflora. Sci Rep. 8(1):11938.

Madhussodanan J. 2021. Should race be a factor in medical risk calculators? Science. 372(6553):380–383.

Mejàre I, Axelsson S, Dahlén G, Espelid I, Norlund A, Tranæus S, Twetman S. 2014. Caries risk assessment: a systematic review. Acta Odontol Scand. 72(2):81–91.

Moynihan PJ, Kelly SA. 2014. Effect on caries of restricting sugars intake: systematic review to inform WHO guidelines. J Dent Res. 93(1):8–18.

National Institutes of Health. 2021. Oral health in America: advances and challenges. Bethesda (MD): US Department of Health and Human Services, National Institutes of Health, National Institute of Dental and Craniofacial Research; [accessed 2022 Dec 20]. https://www.nidcr.nih.gov/sites/default/files/2021-12/Oral-Health-in-America-Advances-and-Challenges.pdf.

Nowak AJ, Dooley D, Mitchell-Royston L, Rust S, Hoffman J, Chen D, Merryman B, Wright R, Casamassimo PS, Mathew T. 2020. A predictive model for primary care providers to identify children at greatest risk for early childhood caries. Pediatr Dent. 42(6):450–461. Erratum in: Pediatr Dent. 2021;43(2):81.

Pattanaporn K, Saraithong P, Khongkhunthian S, Aleksejuniene J, Laohapensang P, Chhun N, Chen Z, Li Y. 2013. Mode of delivery, mutans streptococci colonization, and early childhood caries in three- to five-year-old Thai children. Community Dent Oral Epidemiol. 41(3):212–223.

Quiñonez RB, Kranz AM, Lewis CW, Barone L, Boulter S, O'Connor KG, Keels MA. 2014. Oral health opinions and practices of pediatricians: updated results from a national survey. Acad Pediatr. 14(6):616–623.

Schwendicke F, Splieth CH, Thomson WM, Reda S, Stolpe M, Foster Page L. 2018. Cost-effectiveness of caries-preventive fluoride varnish applications in clinic settings among patients of low, moderate and high risk. Community Dent Oral Epidemiol. 46(1):8–16.

Shi L, Jia J, Li C, Zhao C, Li T, Shi H, Zhang X. 2020. Relationship between preterm, low birth weight and early childhood caries: a meta-analysis of the case-control and cross-sectional study. Biosci Rep. 40(8):BSR20200870.

Singh N, Dubey N, Rathore M, Pandey P. 2020. Impact of early childhood caries on quality of life: child and parent perspectives. J Oral Biol Craniofac Res. 10(2):83–86.

Tanaka K, Miyake Y, Sasaki S. 2009. The effect of maternal smoking during pregnancy and postnatal household smoking on dental caries in young children. J. Pediatr. 155(3):410–415.

US Department of Health and Human Services. 2020. Quality of care for children in Medicaid and CHIP: findings from the 2019 child core set [accessed 2021 July 1]. https://www.medicaid.gov/medicaid/quality-of-care/downloads/performance-measurement/2020-child-chart-pack.pdf.

US Preventive Services Task Force (USPSTF). 2021. Screening and interventions to prevent dental caries in children younger than age five years: US Preventive Services Task Force recommendation statement. JAMA. 326(21):2172–2178.

Weyant RJ, Tracy SL, Anselmo TT, Beltrán-Aguilar ED, Donly KJ, Frese WA, Hujoel PP, Iafolla T, Kohn W, Kumar J, et al; American Dental Association Council on Scientific Affairs Expert Panel on Topical Fluoride Caries Preventive Agents. 2013. Topical fluoride for caries prevention: executive summary of the updated clinical recommendations and supporting systematic review. J Am Dent Assoc. 144(11):1279–1291.

Zero D, Fontana M, Lennon AM. 2001. Clinical applications and outcomes of using indicators of risk in caries management. J Dent Educ. 65(10):1126–1132.