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SYSTEMATIC REVIEW

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A systematic review to inform the development of a Canadian caries risk assessment tool for use by primary healthcare providers

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Abstract

Background: Caries risk assessment (CRA) tools may assist in identifying children at risk of early childhood caries.

Aim: To complete a systematic review of CRA and develop a Canadian CRA tool for preschool children for use in non-dental clinical settings.

Design: Systematic searches of relevant databases were conducted. Potential variables were based on strength of associations (odd ratios, relative risk, hazard ratios, etc), frequency of occurrence, and existing CRA tools. Quality of the evidence assessments were performed by at least two review teams through consensus following GRADE.

Results: Overall, 25 publications met the inclusion criteria, all prospective in design. Based on this review, variables to be considered when developing a new CRA tool for use with preschool children are as follows: age, socioeconomic status, family toothbrushing habits, fluoride exposure, infant feeding practices, dietary habits/behaviours, dental home, caries experience, visible plaque, and enamel defects. The environmental scan identified 22 CRA tools suggesting other additional variables to consider including in a CRA tool, including special healthcare needs, enamel defects, and dental attendance.

Conclusions: This review informed the development of a Canadian CRA tool for use by primary healthcare professionals, which may improve access to oral health assessments and increase interprofessional collaboration.

KEYWORDS

caries risk assessment, community paediatric dentistry, preschool children, screening tool

1 | INTRODUCTION

Despite all the advancements in dental prevention over the past decades, the problem of early childhood caries (ECC) still exists. Evidence suggests that whereas the prevalence of caries among older children, youth, and adults has declined, the prevalence of ECC in the preschool population has increased.[1-3] For many children with ECC, dental surgery under general anaesthesia is the only treatment option.[4] In-hospital day surgery to treat ECC is the most common day surgical procedure in Canada.[5] A 2013 report from the Canadian Institute of Health Information revealed that the

rate of dental surgery to treat ECC in Canada is 12.5/1000 children aged 1-5 years.[5] Furthermore, evidence suggests that dental surgery rates are higher in children living in rural regions and from lower income households, and Indigenous communities.[5] The rates of dental surgery for ECC are even higher in northern regions of Canada (up to 227/1000 children), where many First Nations and Inuit communities are located.[5,6] Unfortunately, this surgical approach fails to address the underlying risk factors for ECC, as many children develop new or recurrent caries within months of surgery.[4] This highlights the importance of implementing an effective prevention regimen to complement restorative care and adopting a risk-based approach to caries management.

The goal of caries risk assessment (CRA) is to develop and provide patient-centred caries prevention and management strategies for the individual. What makes caries risk-based care unique over traditional surgical/restorative approaches to dealing with caries lesions is that there is emphasis on intervening before there is irreversible damage to teeth.[7-9] CRA tools can also be used by non-dental professionals to screen children, determine caries risk, and provide prevention services, including fluoride varnish, oral hygiene instruction, and anticipatory guidance.

Several organizations have developed tools that can be used to help guide practitioners in determining an individual's likelihood of developing caries. These tools provide a means to identify risk factors and behaviours that can promote caries along with protective factors known to minimize the risk of onset.[10] Risk tools help identify whether a child is at low or high likelihood of developing caries, and can guide providers to implement preventive interventions and practices that can help minimize caries risk. These tools help guide the conversation between the dental provider and the parent or caregiver so that key information is obtained to assist in identifying many of the protective and caries causing factors.

One of the limitations of CRA tools, however, is that the majority have not been validated, especially across different population groups. The validity of a tool can be determined by assessing the sensitivity and specificity of the instrument.[11-13] Sensitivity in the context of CRA refers to the capability of the tool to predict future caries risk in someone who does develop caries lesions. It has been suggested that for a CRA tool to be useful, it should have a combined sensitivity and specificity score of at least 160%, and should be relatively well balanced between these two measures.[11] Well-designed and contemporary CRA tools can facilitate clinical dental examinations as they help guide clinicians to review and query parents regarding a multitude of factors that contribute to disease development and progression.[11]

The purpose of this project was to complete a systematic review of CRA and develop a Canadian CRA tool for preschool children for use by non-dental primary healthcare providers and dental providers in non-dental clinical settings.

Why this paper is important to paediatric dentists?

- This review identified several key factors to be considered including in caries risk assessment tools for preschool children.
- Many children face access to primary oral healthcare challenges, highlighting the need for innovative and interprofessional approaches to improve early childhood oral health.
- This new Canadian CRA tool has the potential to improve access to oral health assessments and interprofessional collaboration in the area of young children's oral health.

2 | METHODS

The search strategy was informed by previous search strategies used in other systematic reviews on CRA.[11,12,14-16] Systematic searches were conducted in MEDLINE Ovid, Cochrane Library, EMBASE Ovid, and Scopus in August 2017. Searches were devised using controlled vocabulary where available and keyword terms for three concepts; Dental Caries, Risk Assessment, and Children. A total of 1921 results were gathered and de-duplicated in EndNote, with a final tally of 980 unique articles. All abstracts were reviewed by three teams. Inclusion criteria for selection of articles appear in Table 1. Articles were fully reviewed if an abstract was selected by a minimum of two review teams. For the purpose of this review, only those articles involving children <72 months of age were selected (65 articles). Potential variables to include in the draft CRA tool for use were based on strength of associations (eg, odds ratios, relative risk, hazard ratios), frequency of occurrence in the identified studies and existing CRA tools, and factors that were feasible to include.

Quality of the evidence assessments were performed by at least two review teams through consensus following GRADE.[17] A modified version of a table developed by Gao et al[12] was created to identify and characterize the different variables and factors included in the reviewed CRA tools. Once the initial report was completed, the Office of the Chief Dental Officer (OCDO) of Canada struck a working group of experts and potential users, which examined the body of evidence and critically appraised the report. The working group debated and ultimately recommend factors to include in the drafted CRA tool with the appropriate target audience of primary care providers. Agreement was achieved through consensus. The working group of experts were credentialed members from the Canadian Paediatric

TABLE 1 Inclusion Criteria for Reviewing Articles from Caries Risk Assessment Literature Search (modified from Mejàre et al[19] and Zero et al[29])

Study Design
• Prospective/longitudinal cohort studies OR randomized controlled trial
• Studies using the same sample, but a different prediction model for caries risk, are acceptable
• Studies using ≥1 risk factors/aetiological factors/causative factors as a predictor of caries risk are acceptable (eg, past caries experience; microbiological factors; host factors—enamel defects/hypoplasia, saliva flow rate; diet, socioeconomic; fluoride exposure; oral hygiene)
• Studies only looking at previous caries experience as a predictor of caries risk are acceptable.
Study Sample
• Inclusion criteria for study defined, selection of study sample declared
• Population defined and representativeness of sample understandable (no appearance of selection bias)
• Demographic characteristics of participants described
• Clinical characteristics of participants described
• All participants initially involved should be included.
Methods
• Caries diagnostic criteria described
• Predictor factors/variables are defined
• Validation variables are defined
• Studies involving only 1 dental examiner allowed if the same person completed both baseline and follow-up examinations.
Follow-up Time
• ≥1-y follow-up for primary teeth
• ≥2-y follow-up for permanent teeth.
Outcomes and Analysis
• Caries incidence or caries increment (dentin and/or enamel) reported at the tooth and tooth surface level
• Predictive validity: sensitivity and specificity are reported, relative risk, odds ratio, hazard ratio, caries rate ratio (incidence density ratio), or area under ROC curve. For this systematic review, we will only include articles that reported sensitivities and specificities derived from multivariate analysis, which allows us to compare predictors across included articles.
• Studies on post-eruptive age as a risk factor for caries will be included if caries rate (incidence density) or some other survival analysis is performed or possible to calculate from reported data in study.

Society (CPS), Canadian Academy of Pediatric Dentistry, and the Canadian Association of Public Health Dentistry. Representatives from the Canadian Dental Association, Canadian Dental Hygienists Association, Canadian Dental Assistants Association, Saskatchewan Dental Therapists Association, and the College of Family Physicians of Canada attended as observers. This included a paediatrician, a family physician, two paediatric dentists, and four public health dentists, among other dental professionals along with the Chief Dental Officer and the Senior Policy Advisor in the OCDO. A timeline of the activities in the project is outlined in Table 2.

3 | RESULTS

A total of 25 publications met the inclusion criteria (Table 3).[12,18-40] All were prospective in design, beginning during early childhood or prenatally. Key findings from multivariate analyses in these publications and quality assessments appear in Tables 3 and 4.

3.1 | Sociodemographic and family factors

Of 11 studies that included age as a predictor, five reported that age was significantly associated with future caries risk with odds ratios ranging from 1.1 to 5.0.[22,25,31-33] This would justify including "age" as a variable in a CRA tool.

Three of 16 studies assessing sex reported that males were at greater risk for caries development (HR 1.1, RR 3.0), and one reported that males were at lower risk (HR 0.8).[24,26,38] Thus, there is very limited evidence to suggest including "sex" as a variable in a CRA tool. Additionally, only three of five publications that examined ethnicity indicated that ethnicity was associated with increased caries risk.[24,31,33] One study suggested that both Hispanic (HR 1.8) and African American (HR 1.8) children were at risk, whereas two indicated that Malay (both OR 1.8) children were at risk. Given the limited information on ethnicity and the considerable variability that exists in determining ethnic background of children, there is limited evidence to suggest its inclusion as a variable in a CRA tool.

Six of 11 studies identified that household socioeconomic factors, including low socioeconomic status (SES) (2.38X, OR 10.4),[30,35] deprivation,[27] parental employment status (RRI 11),[26,32] and income (OR 3.3 <$200 000/yr),[41] were significantly associated with caries risk. High SES and having a high household income were protective against caries.[30,41] Based on this evidence, low SES or other indicators of household income and employment should be considered. Only one of three studies reported that the type of housing was associated with caries risk,[27] which may be a proxy for family SES. Another identified that household drinking water sourced from rain, well water, or other non-traditional sources was associated with increased caries risk (OR 2.0).[41] This, however, may be a proxy measure of access to both fluoridated drinking water and SES. Four of seven articles identified parental education level as a risk factor for future caries development; two revealed associations with maternal education (OR 2.5 high school, OR 3.2 >high school) and two with paternal education (OR 0.6, OR 0.7).[31-34,41] Given that parental educational attainment

TABLE 2 Project timeline

Date	Activity
June 2017	University of Manitoba based team contracted by the Office of the Chief Dental Officer (OCDO) of Canada, Public Health Agency of Canada, to undertake CRA project. This included a systematic review and drafting a CRA tool for children <6 y of age primarily for use by non-dental primary healthcare providers.
June-October	Systematic review conducted by team.
November 2017	Completed systematic review report submitted to the OCDO. The report title: *A Systematic Review of Evidence on Caries Risk Assessment for Preschool Children and Recommendations for the Development of a Canadian Caries Risk Assessment Tool for Screening Purposes*.
March 2018	OCDO convenes an expert working group panel with key stakeholder groups to review the report and provide feedback. Expert working group discusses which factors are best suited and should be included in the CRA tool for use in non-dental clinical settings for use by non-dental primary healthcare providers and dental providers. Recommendation made to undertake focus group pilot testing of CRA tool.
May 2018	OCDO contracts the University of Manitoba team to undertake a critical appraisal of the evidence on caries risk in preschool children, focus group pilot testing of the CRA tool for use by primary health care professionals, and to refine the CRA tool based on feedback from stakeholders.
June-September 2018	Trial use of drafted CRA tool at preschool health and wellness fairs and multiple focus group sessions with predominantly non-dental primary healthcare providers. Multiple focus group sessions with 62 predominantly non-dental primary care providers (eg, nurses/nurse practitioners (15), physicians (27), and dieticians (6)) were held in order to obtain feedback to refine the CRA tool.
October 2018	Revised report and feedback from focus group testing to refine CRA tool submitted to OCDO.
November 2018	OCDO convenes a meeting of the expert working group panel to review the revised report and review data obtained from the focus group pilot testing of the CRA tool. Revised CRA tool reviewed.
January 2019	Final report submitted to OCDO including final feedback from the expert working group.
April 2019	French translation completed by the Public Health Agency of Canada.
2019	OCDO of Canada disseminates report to members of the Federal Provincial Territorial Dental Directors Working Group and various provincial and territorial dental and dental hygiene regulators in Canada.
April-December 2019	Endorsement of CRA tool by Canadian Academy of Paediatric Dentistry, Canadian Association of Public Health Dentistry, and Canadian Paediatric Society.
January-February 2020	Launch of online version of Canadian CRA tool <6 y of age. https://umanitoba.ca/CRA_Tool_ENG_Version.pdf Inclusion of CRA tool into online version of Rourke Baby Record.

is likely reflected in household SES, there is limited evidence to suggest it should be incorporated separately into a CRA tool.

Only one of the three studies reported on the age of the child's mother with children whose mothers were <25 years of age (RRI 17) and those ≥35 years of age (RRI 2) being at higher risk for caries.[26] Therefore, there is limited evidence to support including maternal age as a variable in a CRA tool. Meanwhile, three of four studies reported an association with parental smoking; one reported that maternal smoking and two reported that parental smoking was associated with increased caries risk (RRI 15 at 3 years of age).[26,27,32] Overall, there appears to be limited evidence to support the inclusion of parental smoking into a CRA tool.

Few studies reported on the association between special health needs of the child and caries risk. One revealed that acute otitis media and respiratory tract infection at 0-12 months were associated with increased caries risk.[24] Meanwhile, two indicated that children without health problems were at increased risk.[31,33] Four studies reported on the association between prenatal and birth characteristics and caries risk in young children. One study identified that low prenatal vitamin D concentrations during pregnancy were associated with caries in infants (OR 2.0).[22] Another reported that premature delivery (<37 weeks) was associated with lower risk for caries (OR 0.2).[36] Two of five studies revealed that birthweight may be associated with increased caries risk.[26,32] One of these studies reported that low birthweights (<2500 g) (RRI 5) and birthweights ≥4000 g are associated with caries (RRI 19).[26] These findings suggest there is limited evidence to support including any of these variables in a CRA tool.

Parental attitudes and knowledge can also influence childhood oral health. For instance, parents believing that caries is a result of a "tooth worm" was found to lessen the risk for caries in their children.[31] Children of parents who are unaware that a bottle of milk at bedtime is bad for their child's teeth are at increased risk for decay.[31] Another

TABLE 3 Summary of Included Articles in Systematic Review (modified from Mejàre et al[19])

Reference	Age at start (years)	Possible predictors of risk assessed	Outcome in final model	Quality of evidence
Leverett et al 1997[34]	Birth cohort	Prenatal fluoride supplementation Sex	Poisson regression: No significant association of prenatal fluoride supplementation with caries at age 3 to 5 y	⊕⊕⊕⊕ High
Pienihakkinen et al 2004[19]	2 y at baseline	Mutans streptococcus from plaque Previous caries experience d1-3mfs Visible plaque Gingival bleeding Fluoride use Frequency of candy consumption	Mutans streptococcus from plaque (OR 3.9) Previous caries experience d1-3mfs (OR 7.3) Frequency of candy consumption (OR 3.6)	⊕⊕○○Low
Skeie et al 2004[40]	5-y-olds	Previous caries experience	≥1 one caries lesion (d1-5mfs) on proximal surface or molars at 5 y of age (OR 4.4) Total d1-5mfs >one standard deviation above mean at 5 y of age (OR 3.8)	⊕⊕○○Low
Ji et al 2006[21]	1.5 y at baseline	Cariostat completed for each child Breastfeeding Eat snacks while playing Frequency of snacks Brushing assistance by mother Set time for snacks	Risk factors at 18 mo to predict caries at 42 mo: Breastfeeding (OR 3.3) Eat snacks while playing (OR 2.3) Risk factors at 30 mo to predict caries at 42 mo:Eat snacks while playing (OR 1.6) No brushing assistance by mother (1.8)	⊕⊕○○Low
Alaki et al 2008[24]	Birth cohort	Acute otitis media (medical claims) Respiratory tract infections (medical claims) Urinary tract infections (medical claims Race Sex	Acute otitis media and respiratory tract infection at 0-12 mo (HR 1.3) Male (HR 1.1) Hispanic (HR 1.8) African American (HR 1.6)	⊕⊕○○Low
Hong et al 2009[28]	0.5-2 y at baseline (Iowa Fluoride Study birth cohort)	Enamel hypoplasia Sex Childhood illness Gestational age Birthweight Breastfeeding for ≥6 mo Fluoride concentration of home drinking water Average daily fluoride intake Average daily soda pop intake Daily toothbrushing frequency Previous caries experience	Logistic GEE model for caries at age 5 y: enamel hypoplasia (OR 7.6) Dental examination age (OR 7.6) Breastfeeding <6 mo (OR 2.2) Average home tap water fluoride concentration 1.0 ppm (OR 2.4) Logistic GEE model for caries at age 9 y: enamel hypoplasia (OR 5.2) Average daily toothbrushing frequency during 5-9 y old (OR 2.2) Logistic GEE model for caries incidence age 5-9: Previous caries experience (OR 5.1) Average daily fluoride intake during 5-9 y of age (OR 1.9) Average daily toothbrushing frequency during 5-9 y of age (OR 2.0)	⊕⊕○○Low
Warren et al 2009[25]	0.5-2 y at baseline (Iowa Fluoride Study birth cohort)	Age Presence of plaque Presence of *mutans streptococcus* Sugar-sweetened beverage consumption Night-time bottle feeding	Age (OR 1.1) Presence of *mutans streptococcus* (OR 4.4) Sugar-sweetened beverage consumption (OR 3.0)	⊕⊕○○Low

(Continues)

TABLE 3 (Continued)

Reference	Age at start (years)	Possible predictors of risk assessed	Outcome in final model	Quality of evidence
Gao et al 2010[31]	3-6 y	Age Sex Race Country of birth Parents' education level Housing condition Feeding histories Diet habits Oral hygiene Fluoride applications Dental attendance Systemic disease Parental knowledge and attitudes on oral health Plaque pH *Mutans streptococcus* levels Lactobacillus levels Past caries experience	Prediction screening model: Age (OR 1.0) Malay race (OR 1.8) Father's education level (OR 0.6) Months of breastfeeding (OR 1.0) Frequency of between-meal sweets (OR 1.4) No health problems (OR 2.9) Past caries experience (baseline) (OR 7.3) Plaque index (5.1) Full prediction model: Age (OR 1.1) Father's education level (OR 0.6) Months of breastfeeding (OR 1.1) Using fluorides (other than toothpaste) (OR 0.4) No annual dental check-up because teeth did not bother child (OR 0.5) No health problems (OR 2.7) Past caries experience (baseline) (OR 3.9) Plaque index (8.9) *Mutans streptococcus* levels (OR 2.7) Lactobacillus levels (OR 2.3) Average pH (OR 0.01) Risk screening model: Age (OR 1.1) Months of breastfeeding (OR 1.0) Bedtime feeding (OR 1.5) Frequency of between-meal sweets (OR 1.3) Bedtime sweets (OR 1.3) Never lived in non-fluoridated community (OR 0.7) Plaque index (9.1) Full risk model: Age (OR 1.1) Months of breastfeeding (OR 1.0) Plaque index (7.4) *Mutans streptococcus* levels (OR 2.6) Lactobacillus levels (OR 2.1) Average pH (OR 0.02) Community screening model: Age (OR 1.0) Malay race (OR 2.1) Using fluorides (other than toothpaste) (OR 2.6) Parent's belief that 'tooth worm' as reason for caries (OR 0.1) Parents do not know that bedtime milk bottle is bad for teeth (OR 2.0) Child`s number of decayed teeth estimated by parent (OR 12.8)	⊕⊕○○Low

(Continues)

TABLE 3 (Continued)

Reference	Age at start (years)	Possible predictors of risk assessed	Outcome in final model	Quality of evidence
Chankanka et al 2011[30]	≤0.5 y (Iowa Fluoride Study birth cohort)	Powdered beverages Soda pop Juice drinks 100% juice Milk Water only Daily toothbrushing frequency Water fluoride level Proportion of new non-cavitated lesions to surfaces at risk (10% change) Proportion of new cavitated lesions to surfaces at risk (10% change) Socioeconomic status Sex Dentition	General linear mixed models (GLMM) regression for non-cavitated caries: 100% juice exposure General linear mixed models (GLMM) regression for cavitated caries: Powdered beverage exposure 100% juice exposure Multivariate general linear mixed models (GLMM) regression for non-cavitated caries: 100% juice exposure—middle and high frequency (↓37%-50%) Toothbrushing frequency (↓33%) Proportion of new cavitated caries lesions to surfaces at risk (↑110%) High socioeconomic status (↓42%) Multivariate general linear mixed models (GLMM) regression for cavitated caries: 100% juice exposure—high frequency (↓48%) Proportion of new non-cavitated caries lesions to surfaces at risk (↑253%)	⊕⊕○○Low
MacRitchie et al 2012[27]	1-y-olds	Caries experience *Mutans streptococcus* Lactobacillus Yeasts Height Weight Head circumference Immunization status Ethnic origin Illnesses Medication Weaning Use of comforter (ie, soother) Vitamin supplementation Feeding problems Family history Parental employment Parental health Parental smoking Housing status Health visitor assessment if child at risk for caries Deprivation category score Breast/bottle feeding Meals Drinks Snacks Toothbrushing Fluoride supplementation Sociodemographics	Model 1—d1mft >0 at age 4 y ('any caries risk' model): Health visitor opinion of caries risk Deprivation category score Parental smoking Breastfeeding Use of comforter (ie, soother) Model 2—d3mft >0 at age 4 y ('any caries risk' model): Health visitor opinion of caries risk Parental smoking Food and drink at night Model 3—d1mft ≥3 at age 4 y ('high caries risk' model): Type of housing Use of a feeder cup Model 4—d3mft ≥3 at age 4 y ('high caries risk' model): Type of housing Health visitor opinion of caries risk Use of vitamins	⊕⊕○○Low

(Continues)

TABLE 3 (Continued)

Reference	Age at start (years)	Possible predictors of risk assessed	Outcome in final model	Quality of evidence
Gao et al 2013[12]	3 y old	NUS-CRA, Cariogram, AAPD CAT, CAMBRA Age Ethnicity Family socioeconomic status Infant feeding history Diet Fluoride Dental attendance Oral hygiene Past caries White spot lesions Enamel defects Dental appliance Systemic health Medication Salivary flow rate Salivary buffering capacity *Mutans streptococcus* levels Lactobacillus levels	CAT (screening) ≥ high (RR 2.0, 95% CI 1.1-2.5) CAT (screening) excluding ≥ high (RR 1.8, 95% CI 0.99-2.4) CAT (comprehensive) excluding socioeconomic factors (RR 2.2 95% CI 0.95-2.6) CAMBRA (screening) ≥ moderate (RR 2.3 95% CI 1.8-2.5) CAMBRA (screening) ≥ high (RR 2.4 95% CI 2.1-2.5) CAMBRA (comprehensive) ≥ moderate (RR 2.2 95% CI 1.9-2.4) CAMBRA (comprehensive) ≥ high (RR 2.3 95% CI 2.1-2.4) Cariogram (screening) ≥38.5% chance of caries (RR 2.2 95% CI 1.9-2.3) Cariogram (comprehensive) ≥37.6% chance of caries (RR 2.2 95% CI 2.0-2.4) NUS-CRA (screening) ≥32.8% chance of caries (RR 2.5 95% CI 2.3-2.5) NUS-CRA (comprehensive) ≥35.2% chance of caries (RR 2.5 95% CI 2.4-2.6)	⊕⊕○○Low
Hallett and O'Rourke 2013[39]	5- to 10-y-olds (assessment included both primary and permanent teeth though)	CariScreen reading (to measure visible light release from dental plaque) *Mutans streptococcus* reading (CariCult) Visible plaque Visible cavitations present Fillings within previous 3 y Reduced saliva flow Exposed dentin Deep enamel pits and fissures Radiographic proximal lesions White spot enamel lesions (incipient caries) Orthodontic appliances	Visible cavitations (multivariate mean 3.9 95% CI 3.0-4.9) Reduced saliva flow (multivariate mean 3.6 95% CI 2.5-4.7) Orthodontic appliances (multivariate mean 4.2 95% CI 2.5-5.9)	⊕⊕○○Low
Schroth et al 2014[22]	Birth cohort. Assessed factors prenatally and in infancy	Low annual income Child's health status Infant's teeth being cleaned or brushed Enamel hypoplasia Household employment Government assistance (ie, social assistance) Infant age at time of dental examination Bottle feeding Breastfeeding Season Prenatal vitamin D level	Enamel hypoplasia (OR 8.9) Infant age (≥14 mo) (OR 5.0) Prenatal vitamin D level (OR 2.0)	⊕⊕○○Low

(Continues)

TABLE 3 (Continued)

Reference	Age at start (years)	Possible predictors of risk assessed	Outcome in final model	Quality of evidence
Abanto et al 2014[38]	1- to 12-y-olds (assessment included both primary and permanent teeth though)	Caries risk Gingival bleeding index Dental plaque index Caries experience Lesion activity assessment Number of teeth with active non-cavitated lesions Sex Age Caregiver of child Use of dental floss Follow-up dental visits	Survival analysis for new initial caries lesions (adjusted model): Past caries experience (dmft index) (HR 1.9 95% CI 1.4-2.7) Follow-up dental visits (HR 0.2 95% CI 0.1-0.6) Number of teeth with active non-cavitated lesions (HR 9.5 95% CI 5.6-16.2) Survival analysis of active initial lesions (adjusted model): Number of teeth with active non-cavitated lesions (HR 1.3 95% CI 1.1-1.5) Male (HR 0.8 95% CI 0.6-0.9) Follow-up dental visits (HR 0.1 95% CI 0.05-0.1)	⊕⊕○○Low
Peltzer et al 2014[41]	Birth cohort. Assessed factors prenatally and in infancy. First dental examination at 2 y	Drinking water in household Birthweight Height at 6 mo Smoking during pregnancy Secondary smoke (at 1 y) Mother had dental cavitation(s) at baseline Mother's age at birth Mother's education at birth Household income Religious affiliation Single parent Family size Sex of child First child in family Psychological distress of mother Psychological distress of father Parenting style Family distress Family support index Spousal relationship (mother) index Spousal relationship (father) index Infant feeding (at 6 mo) Nocturnal feeding at 12 mo Introduction of soft drinks (at 12 mo) Sleeping with bottle (at 30 mo) Brushing teeth in past 2 wk (at 12 mo) Sweet candy in days in a week (at 30 mo) Brush with toothpaste (at 12 mo) Brushing teeth (at 26 mo) Previous dental visit (at 30 mo)	Drinking water in household (rain, well, or other) (OR 2.0) Mother completed high school (OR 2.5) Mother completed post-high school (OR 3.2) Household income $100 000-$199 999 (OR 0.4) Household income ≥ $200 000 (OR 0.3)	⊕⊕○○Low

(Continues)

TABLE 3 (Continued)

Reference	Age at start (years)	Possible predictors of risk assessed	Outcome in final model	Quality of evidence
Gao et al 2014[33]	3- to 5-y-olds	Parent's education level Type of housing Age Sex Ethnicity Feeding history Diet habits Oral hygiene Fluoride exposures Dental attendance Parental knowledge, attitudes, and self-efficacy in protecting children's teeth *Mutans streptococcus* levels Lactobacillus levels Past caries experience	*Mutans streptococcus* levels: Dentocult score 1 (RR 2.0) Dentocult score 2 (RR 3.4) Dentocult score 3 (RR 4.6) Lactobacillus levels: Dentocult score 1 (RR1.9) Dentocult score 2 (RR 2.7) Dentocult score 3 (RR 2.7) Past caries experience (RR 1.6) Model with *mutans streptococcus*: Age (months) (OR 1.1) Malay race (OR 1.8) Father's education (OR 0.7) Months of breastfeeding (OR 1.0) Fluoridated toothpaste (OR 0.6) No health problems (OR 2.4) Past caries experience (OR 4.3) Plaque index (OR 5.2) *Mutans streptococcus* (OR 2.2) Model with Lactobacillus: Age (months) (OR 1.0) Father's education (OR 0.6) Months of breastfeeding (OR 1.0) Frequency of sweet (OR 1.4) Fluoridated toothpaste (OR 0.6) No health problems (OR 2.4) Past caries experience (OR 4.8) Plaque index (OR 5.2) Lactobacillus (OR 1.9) Model with *mutans streptococcus* and Lactobacillus: Age (months) (OR 1.1) Father's education (OR 0.6) Months of breastfeeding (OR 1.1) Fluoridated toothpaste (OR 0.6) No health problems (OR 2.2) Past caries experience (OR 3.0) Plaque index (OR 5.2) *Mutans streptococcus* (OR 2.1) Lactobacillus (OR 1.9)	⊕⊕○○Low

(Continues)

TABLE 3 (Continued)

Reference	Age at start (years)	Possible predictors of risk assessed	Outcome in final model	Quality of evidence
Yokomichi et al 2015[26]	<1 y of age	Sex Birthweight Age of mother Gestational age Birth order Number of teeth (at 18 mo) Parental employment Bottle use (at 18 mo) Dental fluoridation experience (at 3 y) Parental smoking (at 3 y) Sibling <6 y (at 3 y) Someone who supports child rearing (at 3 y) Parental brushing child's teeth (at 18 mo) Parental brushing child's teeth (at 3 y) Drinking cow milk (at 18 mo) Drinking cow milk (at 3 y) Irregular meals and snacks (at 18 mo) Irregular meals and snacks (at 3 y) Watching TV or video daily (at 3 y)	Boys (RRI 3) Birthweight ≥4000 g (RRI 19) Birthweight <2500 g (RRI −5) Age of mother <25 (RRI 17) Age of mother ≥35 (RRI 2) Not first-born child (RRI 26) 14-20 teeth at 18 mo (RRI 13) Both parents unemployed (at 3 y) (RRI 11) Bottle use (at 18 mo) (RRI 4) Parental smoking (at 3 y) (RRI 15) No one supports child rearing (at 3 y) (RRI 17) Parents sometimes or never brushing child's teeth (at 18 mo) (RRI 18) Parents sometimes or never brushing child's teeth (at 3 y) (RRI 22) Drinking cow milk (at 18 mo) (RRI −12) Drinking cow milk (at 3 y) (RRI-5) Irregular meals and snacks (at 18 mo) (RRI 16) Irregular meals and snacks (at 3 y) RRI 16	⊕⊕○○Low
Ghazal et al 2015[36]	<2 y old	Age Sex Delivery type (standard, C-section, forceps, other) Premature delivery Birthweight Allergies Chronic systemic medical condition Acute illness in previous 6 mo Breast fed Bedtime bottle Bottle use Beverages consumed (type, frequency, timing) Methods of drinking liquids other than water Amount of beverages consumed Toothbrushing Toothpaste Dental history Sources of drinking water Use of vitamin drops or tablets with fluoride History of dental problem Reason for last dental visit Presence of regular dentist	Model A – 3 y incidence: Premature delivery (<37 wk) (OR 0.2) 100% juice consumption ≥1 time per day (OR 0.4) Model B—Incidence from age 2 to 3 y: Greater daily frequency of toothbrushing at baseline (OR 0.3) Previous visit to dentist (OR 4.6)	⊕⊕○○Low

(Continues)

TABLE 3 (Continued)

Reference	Age at start (years)	Possible predictors of risk assessed	Outcome in final model	Quality of evidence
Wagner and Heinrich-Weltzien 2016[29]	Birth cohort (<12 mo of age)	Caries experience Sex Migration background Socioeconomic status Single parent Mother/primary caregiver has active caries Family early childhood caries burden Preterm birth General disease/special healthcare needs Medication Systemic antibiotic medication No use of vitamin D supplements Child has >3 between-meal sugar-containing snacks/beverages per day Child is put to bed with a bottle containing natural or added sugar Child's teeth were brushed daily with fluoridated toothpaste Child receives topical fluoride from health professional Child has dental home/regular dental care Enamel defects Plaque on teeth	Model of associations between caries experience of children and low socioeconomic status, family early childhood caries burden, systemic antibiotic medication, no use of vitamin D supplements, receives topical fluoride from health professional, child has regular dental care, and child has plaque on teeth: Family early childhood caries burden (OR 2.2) No use of vitamin D supplements (OR 1.9) Child has regular dental care (OR 0.5) Plaque on teeth (OR 6.5)	⊕⊕○○Low
Hultquist & Bagesund 2016[18]	1-y-olds	Siblings Siblings have dental caries Child eats or drinks anything except water at night Child still breastfed Child has illness/disease Child regularly takes medication Child drinks anything except water between meals Parent brushes child's teeth Number of teeth visible in mouth *Mutans streptococcus* counts	Siblings have dental caries (OR 4.8) Child eats or drinks at night (OR 3.0) Child drinks anything except water between meals (OR 7.1) High level of *mutans streptococcus* (score 2-3) (OR 3.4)	⊕⊕○○Low

(Continues)

TABLE 3 (Continued)

Reference	Age at start (years)	Possible predictors of risk assessed	Outcome in final model	Quality of evidence
Lin & Lin 2016[20]	Mean age 4 y at baseline who underwent paediatric dental surgery for ECC	Gender Age Father's education level Mother's education level Diet frequency per day Snacks/drinks between meals Bedtime sweet without brushing Brushing by child or parent Frequency of tooth brushing Buffer capacity of saliva *Mutans streptococcus* count Lactobacillus count Plaque index (oral hygiene status) Score of caries risk assessment	Score of caries risk assessment using Cariogram (OR 1.1)	⊕⊕○○Low
Wang et al 2016[23]	3- to 5-y-olds	Caries status (dmft) Sex Age Parental education Parental occupation Income Eating habits Oral hygiene behaviours	Caries experience (OR 5.0) Parent helps child brush teeth daily (OR 0.9) Parents consider caries in primary teeth need to be treated (OR 1.3)	⊕⊕○○Low
Correa-Faria et al 2016[37]	4- to 7-y-olds	Sex Caries Oral hygiene Place of residence Mother's education level Household income Age	Previous caries experience (RR 1.5)	

(Continues)

TABLE 3 (Continued)

Reference	Age at start (years)	Possible predictors of risk assessed	Outcome in final model	Quality of evidence
Wagner and Heinrich-Weltzien 2017[35]	Birth cohort (<12 mo of age)	Sex Age Migration background Socioeconomic status Age at start of tooth brushing Frequency of tooth brushing Supervision of tooth brushing/regular second brushing by parent Use of fluoride salt and/or fluoride toothpaste Age at first dental visit Number of dental visits/year Application of fluoride varnish Frequency of in-between meals Consumption of sugar-containing snacks/beverages per day Duration of breastfeeding Duration of bottle feeding Previous caries experience	Model of association between caries experience in children and low socioeconomic status, start of tooth brushing, supervision/regular second brush by parent, frequency of tooth brushing, first dental visit, frequency of dental visits, application of fluoride varnish, frequency of in-between meals, sugar-containing snacks/beverages per day, duration of breastfeeding >1 y, duration of bottle feeding >1 y: Low socioeconomic status (OR 10.4) Started brushing in first year of life (OR 0.2) Supervision/regular second tooth brushing by parent (OR 0.1) ≥2 dental visits per year (OR 0.1) Duration of breastfeeding/bottle feeding >1 y (OR 6.2)	⊕⊕○○Low
Bernabe et al 2017[32]	1 y	Sex Birth order Birthweight Maternal age at birth Maternal education Breastfeeding duration Marital status Maternal smoking Parental employment Area deprivation Child's toothbrushing frequency	Age (coefficient 0.16, 95% CI 0.12-0.21) Final linear mixed-effects model: Birthweight ($P = .039$) Parental employment ($P < .001$) Maternal smoking ($P = .006$) Maternal education ($P < .001$)	⊕⊕○○Low

Abberviations: HR, Hazard Ratio; OR, Odds Ratio; RR, Relative risk.

TABLE 4 Level of association between risk factor and caries

Factor/Variable	No. of Studies that include that factor	No. of studies that show significant association	Range of effect sizes	Expert opinion on inclusion of this factor (Yes/No)
Sociodemographic and family factors				
Age[22,25,31-33]	11	5	OR 1.1 - 5.0	Yes
Sex[24,26,38]	16	3	HR 1.1 - 3.0	No
Ethnicity[24,31,33]	5	3	HR 1.1, 1.8 OR 1.8, 2.1	No
Household socioeconomic factors[26,27,30,32,35,41]	11	6	2.38X OR 0.3-10.4 RRI 11 $P < .001$	Yes
Housing type[27]	3	1	Data not available	No
Household water[41]	2	1	OR 2.0	No
Parental education level [31-33,41]	4	7	OR 0.6-3.2 $P < .001$	No
Maternal age [26]	3	1	RRI 2 , RRI 17	No
Parental smoking[26,27,32]	4	3	RRI 15 , $P = .006$	No
Acute otitis media [24]	1	1	HR 1.3	No
No health problems [31,33]	2	2	OR 2.2 - 2.9	No
Prenatal vitamin D[22]	1	1	OR 2.0	No
Premature delivery (<37 wk)[36]	2	1	OR 0.2	No
Birthweight[26,32]	5	2	RRI −5, RRI 19 $P = .039$	No
Parent attitude [23,31]	3	2	OR 0.1-2.0	No
Not first-born child[26]	1	1	RRI 26	No
Lack support with child-rearing[26]	1	1	RRI 17	No
Family ECC burden[29]	1	1	OR 2.2	No
Siblings have dental caries[18]	1	1	OR 4.8	No
Behavioural factors				
Frequency of toothbrushing [28,30,36]	9	3	OR 2.0 - 4.6	Yes
Initiating brushing in the first year of life[35]	1	1	OR 2.0	No
Parental supervision or assistance with toothbrushing [21,23,26,35]	6	4	OR 0.1 - 1.8, RRI 18	Yes

(Continues)

TABLE 4 (Continued)

Factor/Variable	No. of Studies that include that factor	No. of studies that show significant association	Range of effect sizes	Expert opinion on inclusion of this factor (Yes/No)
Exposure to fluorides[28,31,33]	11	3	OR 0.4 - 2.6	Yes
Evidence of breastfeeding and duration of breastfeeding (BF)[21,27,28,31,33]	10	5	OR 1.0 - 6.2	Yes
Comforter or Soother [27]	1	1	Data not available	No
Snacking habits and behaviours [19-21,26,27,30,31,33]	11	8	OR 1.4 - 7.1 RRI −5, RRI −12, RRI 16	Yes
Dental home and dental attendance behaviours [28,29,31,35,36,38]	10	6	OR 0.1 - 7.6 HR 0.1	Yes
Clinical factors				
Previous caries experience [19,23,30,31,33,37-40]	25	9	OR 3.9, OR 4.3, OR 4.4, OR 5.0, OR 5.1, OR 7.3, OR 7.6, HR 1.9, RR 1.5, RR 1.6	Yes
Active non-cavitated caries lesions[38]	1	1	HR 9.5	Yes
Dental plaque or plaque index [20,22.36]	7	3	OR 5.2, 6.5, 8.9	Yes
Enamel hypoplasia [22,28]	5	2	OR 8.9, OR 5.2	Yes
Having 14-20 teeth by 18 mo[89]	1	1	RRI 4	No
Orthodontic appliance[39]	1	1	Multivariate mean 4.2, 95% CI 2.5-5.9	No
Salivary and bacterial factors				
Saliva and oral pH[31,39]	4	2	OR 0.01, 0.02 multivariate mean 3.6	No
Mutans streptococcus[18,19,25,31,33]	9	5	OR 2.1-4.4	Yes

study reported that parents who consider it necessary to treat caries involving primary teeth are more likely to have a child at risk for future caries.[23] Due to this limited evidence, assessments of parental knowledge and attitudes towards early childhood oral health should not be included in a CRA tool.

3.2 | Behavioural factors

3.2.1 | Oral hygiene behaviours

Several studies examined toothbrushing behaviours and its association with caries risk. Three of nine studies reported that toothbrushing frequency was associated with developing caries with odds ratios ranging from 2.0 to 4.6.[28,30,36] One study reported that initiating brushing in the first year of life was protective (OR 0.2) and reduced the risk of caries.[35] Four of six studies reported on the association between parental supervision and assistance with child toothbrushing with an OR ranging from 0.1 to 1.8 and a RRI 18.[21,23,26,35] One of these studies suggested that parents helping the child brush their teeth daily (OR 0.9) was associated with increased caries risk.[23] The other three, however, concluded that regular parent-supervised toothbrushing was protective against caries (OR 0.1),[35] whereas no or infrequent parental involvement was associated with future caries development (OR 0.9-1.8).[21,23] This suggests that a question about the frequency of toothbrushing and/or the involvement of parents in supervising daily toothbrushing may be helpful if included in a CRA tool.

Exposure to fluoride was also reported in some of the studies. One study reported that use of fluoridated toothpaste was protective (OR 0.6).[33] Another study indicated that average daily fluoride intake was associated with caries (OR 1.9).[28] Access to fluoridated tap water is also a predictor of caries risk as fluoride levels in drinking water (OR 2.4)[28] and fluoridated water (OR 0.7)[31] can influence caries development. One of these studies also reported that fluoride use, other than toothpaste, is also associated with caries risk (OR 0.4).[31] This study, however, did note that this could be a result of high caries burden at baseline.[31] Based on this evidence, an assessment of exposure to sources of fluoride should be included in a CRA tool.

3.2.2 | Infant feeding behaviours

Several studies reported on the association between infant feeding behaviours and caries risk, namely breastfeeding, feeding duration, and bottle feeding. Five of 10 studies provided evidence on breastfeeding and duration of breastfeeding.[21,27,28,31,33] Two studies revealed that breastfeeding was associated with an increased risk of caries.[21,27] Three other studies on breastfeeding duration concluded that the number of months of breastfeeding (OR 1.0)[31,33] and breastfeeding for fewer than 6 months (OR 2.2)[28] were associated with increased caries risk. Another study did not differentiate between feeding method, but reported that the duration of breast and bottle feeding for greater than one year increased the risk for caries (OR 6.2).[35] Only one study revealed that bottle use at 18 months of age was associated with caries (RRI 18).[26] Another indicated that bedtime feeding was associated with caries risk (OR 1.5)[31] and the use of a feeding cup was also reported to increase childhood risk for caries.[27]

Based on this evidence, it would be prudent for a newly developed CRA tool to inquire about infant feeding practices and durations, but to separately ask about breastfeeding and bottle feeding.

As only one study reported that the use of a comforter or soother was associated with increased caries risk,[27] this variable should not be included in a CRA tool.

3.2.3 | Dietary habits and behaviours

Snacking habits and behaviours were identified in 8 of 11 studies. One study indicated that irregular meals and snacks increased the risk for caries (RRI 16 at 18 months).[26] Another revealed that eating snacks while playing increased risk (OR 2.3).[21] A third reported that the frequency of between-meal sweets was associated with greater risk for future caries development (OR 1.3).[31]

Two studies looked at the frequency of intake of sweets and reported associations with increased risk for decay; one indicated that the frequency of candy consumption was a risk factor (OR 3.6),[19] whereas the other revealed that the frequency of sweets increased risk (OR 1.4).[33] Three studies also mentioned that consuming food and drink at night increased children's risk for caries.[18,27,31] Eating and drinking food at night (OR 3.0)[18,27] and sweets at bedtime (OR 1.3)[31] were all reported to increase caries risk.

The consumption of cow's milk was found to be protective against caries at 18 months (RRI −12) and at 3 years (RRI −5). [26]Additionally, drinking anything except water between meals was associated with caries risk (OR 7.1).[18] Sugar-sweetened beverage consumption (OR 3.0),[25] use of powdered beverages,[30] and exposure and frequency of 100% juice (OR 0.4)[30,36] were associated with future decay.

Based on this evidence, dietary practices and habits should be integrated into a CRA tool. This includes the frequency of snack foods and sugary drinks between meals.

Only two studies revealed data on the use of vitamins. One study reported that the use of vitamins was associated with an increased risk for caries,[27] whereas the other indicated that the absence of vitamin D supplementation (OR 1.9) increased a child's risk for decay.[29]

3.2.4 | Dental home and dental attendance behaviours

Dental home and dental attendance behaviours were identified in 6 of 10 of the studies. Three studies reported that regular dental care is protective against caries.[29,35,38] One study indicated that follow-up visits to the dentists were protective (HR 0.1), another indicated regular dental care was protective (OR 0.5), whereas the other revealed that two or more visits per year were protective against caries (OR 0.1).[29,35,38] An additional study reported that not seeking annual dental check-ups for the child because their teeth did not bother the child was protective against caries.[31] Meanwhile, another study reported that children with previous visits to the dentist were at greater risk for caries (OR 4.6).[36] The author noted that this association might be due to parent-identified need to see a dentist and/or referrals to dentists by the study team.[36] Hong et al[28] reported that the child's age at the time of their dental examination was predictive of caries (OR 7.6).

Based on this evidence, a history of dental visits and presence of a dental home should be considered in a CRA tool.

3.3 | Clinical factors

Previous caries experience was the most commonly identified factor from the included studies with nine of 25 reporting its association with increased caries risk.[19,23,30,31,33,37-40] Another reported that the number of teeth with active non-cavitated caries lesions was also associated with future caries development (HR 9.5).[38] Therefore, there is ample evidence to include previous caries experience in a CRA tool for preschool children.

The next most common clinical variable was the presence of dental plaque or plaque index with an OR of 6.5, 8.9, and 5.2, respectively.[29,31,33] Any newly developed instrument should include an assessment of visible dental plaque. Only two of the studies reported that enamel hypoplasia was a significant risk factor for future caries (OR 8.9 & 5.2).[22,28] Enamel hypoplasia, however, has often been overlooked in past caries studies. Fortunately, there is growing recognition that enamel hypoplasia increases the risk for caries. Therefore, enamel defects, including enamel hypoplasia, could be considered for inclusion in a newly developed CRA tool.

3.4 | Salivary and bacterial factors

Two of four studies were found to report significant associations between saliva and oral pH and caries risk. One reported that an average oral pH (stimulated saliva flow) was protective against caries development (OR 0.2),[31] and the other revealed that reduced salivary flow increased the risk for caries (multivariate mean 3.6, 95% CI 2.5-4.7).[39] Based on this limited information, there is little value in adding saliva flow and oral pH as variables in a newly developed CRA tool for preschool children, especially for use by non-dental professionals.

Five of nine studies reported that levels of mutans streptococci were significantly associated with future caries development with OR ranging from 2.1 to 4.4, suggesting that consideration of this variable is warranted in CRA instruments.[18,19,25,31,33] Meanwhile, only two of five studies revealed an association between lactobacillus levels and future caries risk.

3.5 | Environmental Scan of Caries Risk Assessment (CRA) tools for children <6 years of age

An environmental scan of existing CRA tools for children <6 years of age was also conducted. A total of 22 CRA tools were identified (Table 5). Although the majority are paper-based, some are electronic. These tools vary in formatting, phrasing of questions, and how responses are used to assign a level of risk. Overall, based on this environmental scan it would be prudent to consider including the following variables when developing a new CRA tool for use with preschool children:

Sociodemographic: Child's age, caries experience of the child's caregiver or siblings, family SES, and special healthcare needs of the child.
Behavioural: Dietary habits and practices, infant feeding histories and behaviours, oral hygiene and toothbrushing habits and behaviours, exposure to fluorides, dental attendance, and dental visit history.
Clinical: Past caries experience of the child, active caries (cavitated or non-cavitated), incipient lesions, presence of plaque, and enamel defects, including enamel hypoplasia.

4 | DISCUSSION

This systematic review identified risk factors for caries in preschool-aged children who informed the development of a Canadian paediatric CRA tool. Based on this systematic review, several sociodemographic, behavioural, and clinical variables could be incorporated into a new CRA tool for use with preschool children. Sociodemographic factors to consider include child's age and SES of the family (ie, low SES and household income, parental education level). It is well recognized that the risk for caries increases as children get older as they have more teeth and these teeth have been subjected

TABLE 5 Inventory of identified caries risk assessment tools for children <6 y of age

Factors	ADA	AAPD (age 0-3)	AAPD (age 0-5)	AAP	Bankel	CAB	CAMBRA	CF	CMS
Sociodemographic									
Age	✓			✓			✓		✓
Ethnicity									
Family SES	✓	✓	✓	✓					
Recent immigrant		✓	✓						
Special health needs	✓	✓	✓	✓			✓	✓	
Caries experience of caregiver/siblings	✓	✓	✓	✓			✓	✓	
Educational level of caregivers/health literacy							✓		
Behavioural									
Infant feeding history		✓	✓	✓	✓		✓	✓	
Diet	✓	✓	✓	✓	✓	✓	✓	✓	✓
Fluoride	✓	✓	✓	✓		✓	✓		✓
Dental attendance	✓	✓	✓	✓				✓	
Parental attitudes/beliefs								✓	
Toothbrushing habits		✓	✓	✓			✓		✓
Clinical									
Oral hygiene/ plaque	✓	✓	✓	✓		✓	✓	✓	✓
Past caries		✓	✓	✓	✓	✓	✓	✓	✓
White spot lesions or active caries (cavitated/ non-cavitated)	✓	✓	✓	✓	✓	✓	✓	✓	✓
Enamel defects		✓	✓				✓		
Dental appliance	✓							✓	
Systemic health						✓	✓	✓	
Medication							✓	✓	
Other oral concerns (eg, gingivitis)				✓					
Protective factors (eg, sealants)									
Salivary and Bacterial									
Saliva flow	✓					✓	✓	✓	
Saliva buffering capacity			✓						
Mutans streptococci			✓		✓		✓		
Lactobacilli							✓		
Reduced pH									

Factors	CG	DCRAM	EBHnow (McGill)	FDI	Maine	MSB	NUS	PRAT
Sociodemographic								
Age			✓	✓	✓		✓	✓
Ethnicity		✓					✓	
Family SES		✓		✓			✓	
Recent immigrant		✓					✓	
Special health needs			✓					
Caries experience of caregiver/siblings		✓	✓	✓	✓	✓		

(Continues)

TABLE 4 (Continued)

Factors	CG	DCRAM	EBHnow (McGill)	FDI	Maine	MSB	NUS	PRAT
Education level of caregivers/health literacy				✓			✓	
Behavioural								
Infant feeding history		✓	✓			✓	✓	✓
Diet	✓	✓	✓	✓		✓	✓	✓
Fluoride	✓	✓	✓	✓		✓	✓	
Dental attendance			✓		✓	✓	✓	
Parent attitudes/beliefs		✓				✓	✓	
Toothbrushing habits		✓			✓	✓		✓
Clinical								
Oral hygiene/ plaque	✓	✓	✓	✓	✓		✓	✓
Past caries	✓		✓	✓	✓	✓	✓	✓
White spot lesions or active caries (cavitated/ non-cavitated)	✓	✓	✓	✓	✓		✓	
Enamel defects			✓					
Dental appliance			✓					
Systemic health	✓	✓	✓				✓	
Medication	✓	✓		✓				
Other oral concerns (eg, gingivitis)	✓		✓		✓			
Protective factors (eg, sealants)				✓				
Salivary and Bacterial								
Saliva flow	✓			✓				
Saliva buffering capacity	✓			✓				
Mutans streptococci	✓	✓	✓				✓	
Lactobacilli	✓	✓	✓				✓	
Reduced pH				✓			✓	

Factors	SSC	Texas (6 –35 mo)	Texas (3-5 y)	UCC (Ireland)	WesternU CDM	Total
Sociodemographic						
Age	✓	✓	✓	✓		13
Ethnicity						2
Family SES						7
Recent immigrant						4
Special health needs		✓	✓		✓	10
Caries experience of caregiver/ siblings		✓	✓		✓	14
Education level of caregivers/Health literacy						3
Behavioural						
Infant feeding history		✓	✓		✓	14
Diet	✓	✓	✓	✓	✓	21
Fluoride		✓	✓	✓	✓	17
Dental attendance		✓	✓		✓	12
Parent attitudes/beliefs						4
Toothbrushing habits				✓		10

(Continues)

TABLE 4 (Continued)

Factors	SSC	Texas (6 −35 mo)	Texas (3-5 y)	UCC (Ireland)	WesternU CDM	Total
Clinical						
Oral hygiene/ plaque	✓	✓	✓		✓	19
Past caries	✓	✓	✓	✓	✓	20
White spot lesions or active caries (cavitated/Non-cavitated)	✓	✓	✓	✓	✓	20
Enamel defects		✓	✓	✓		7
Dental appliance					✓	4
Systemic health				✓	✓	9
Medication						5
Other oral concerns (eg, gingivitis)		✓	✓	✓		7
Protective factors (eg, sealants)				✓		2
Salivary and Bacterial						
Saliva flow	✓	✓	✓		✓	10
Saliva buffering capacity	✓					3
Mutans streptococci	✓					8
Lactobacilli	✓					6
Reduced pH						2

Abbreviations: AAP, American Academy of Pediatrics; AAPD, American Academy of Pediatric Dentistry (AAPD); ADA, American Dental Association; Bankel, Bankel et al; CAB, Cabral, Hilgert, Faber, & Leal et al (University of Brasilia); CAMBRA, Caries Management by Risk Assessment; CF, CariFree; CG, Cariogram (electronic programme); CMS, Caries Management System; DCRAM, Dundee Caries Risk Assessment Model; EBHnow, (McGill University) Online Search Engine for CRA; FDI, World Dental Federation; Maine, Maine Oral Health Risk Assessment and Referral Tool; MSB, My Smile Buddy (electronic iPad-based programme); NUS, National University of Singapore Caries Risk Assessment; PRAT, Pediatric Risk Assessment Tool (Shenkin et al) Academy of General Dentistry; SSC, Sugar Snack Caries Risk Test; Texas, Texas Department of State Health Services; UCC, University College Cork (Ireland); WesternU (CDM) , AxiUm Electronically Modified-Caries Risk Assessment Form 0-5 y of Age.

to longer periods of demineralization as compared to younger children. Although SES should be included in CRA tools, it is important to recognize that collecting household income information is a sensitive matter, and not all parents and caregivers may feel comfortable providing such information.

Behavioural factors to consider include toothbrushing habits with fluoridated toothpaste (ie, frequency, involvement of parents in supervising daily toothbrushing), exposure or lack of exposure to fluorides (ie, fluoridated toothpaste, community water fluoridation), breastfeeding (ie, frequency, duration >12 months), bottle feeding (ie, frequency, duration >12 months, use at bedtime), dietary habits and behaviours (ie, snacking and drinking between meals, intake of sugary beverages, intake of sweets), and the existence of a dental home and dental attendance history (ie, child has dental home, regular dental visits). Breastmilk provides all the energy and nutrients that the infant needs according to the Dietary Reference Intakes from Health Canada, and the World Health Organization recommends exclusive breastfeeding for the first 6 months after which infants should then be offered nutrient-dense and safe complementary foods, along with continued breastfeeding.[42,43] Due to these recommendations, it may be the best not to include questions about feeding history in a CRA tool intended for use by non-dental providers so that misconceptions about breastfeeding and caries are not perpetuated.

Additionally, clinical factors such as the caries experience of the child (ie, past and current caries experience, past treatment of caries), and presence of visible plaque are important to assess. Although developmental defects of enamel (eg, enamel hypoplasia) are an important risk factor, they are not easily identified and thus not practical or realistic to include in a CRA instrument intended for use by non-dental providers. A recent study reported that many dentists are unable to accurately recognize developmental defects of enamel revealing a need for further training and calibration.[44] Therefore, before we expect non-dental providers to screen for such defects, the dental profession needs to ensure its members are appropriately trained. As assessments of saliva flow and bacterial levels are essentially limited to clinical settings and are predictive of future caries risk, CRA tools that are designed for screening purposes and for use by non-dental professionals in non-clinical settings should not include assessments of these variables.[31,33] Further, assessing cariogenic bacterial levels is not feasible or possible for a CRA tool developed for screening purposes and for use by non-dental professionals.

Since this systematic review was completed in the fall of 2017, we recognize that there have been additional publications that would have met our inclusion criteria. Some of these publications have confirmed our original findings, whereas others have made some new discoveries. Not surprising, one

Chinese study reported that high plaque mutans streptococci levels and past caries experience were associated with new caries development.[45] A 2018 study reported that caesarean delivery, parental smoking, siblings with caries, and drinking juice were associated with increased caries risk.[46] Similarly, a US study reported that prenatal and partner smoking were associated with increased caries experience in preschool children.[47] A fourth publication reported that preterm birth and small for gestational age at birth were associated with a higher risk for caries at 5 years of age.[48] Another revealed that brushing less than twice daily at 2 years of age and difficulties in performing brushing at 2 and 3 years of age were associated with greater caries risk.[49] Given the emerging discoveries, our team intends to update our systematic review in 2022 by reviewing all of this new evidence.

This systematic review was undertaken at the request of the OCDO of Canada at the Public Health Agency of Canada (PHAC). The OCDO convened important interprofessional stakeholder meetings to discuss the findings from this systematic review with participants from the OCDO, the Canadian Paediatric Society (CPS), Canadian Academy of Pediatric Dentistry, and the Canadian Association of Public Health Dentistry. Representatives from the Canadian Dental Association, Canadian Dental Hygienists Association, Canadian Dental Assistants Association, Saskatchewan Dental Therapists Association, and the College of Family Physicians of Canada attended as observers. Participants discussed questions that should be included in a future Canadian CRA tool for preschool children.

Our team was subsequently contracted by the OCDO at PHAC to develop this Canadian CRA tool for children <6 years for use by non-dental primary care providers and dental providers in non-dental clinical settings.[50,51] This 6-item tool is based on evidence from a systematic review of the literature and of existing paediatric CRA tools. We undertook focus group testing with 62 non-dental primary care providers (eg, nurses/nurse practitioners (15), physicians (27), dieticians (6)) to refine the tool. The OCDO, CPS, Canadian Academy of Pediatric Dentistry, and Canadian Association of Public Health Dentistry have all endorsed this tool (http://umanitoba.ca/CRA_Tool_ENG_Version.pdf). It has also been added into the online Rourke Baby Record©. A pilot validation of this CRA tool is underway and funded by the Network for Canadian Oral Health Research. Funding from the Canadian Institutes of Health Research now enables us to implement the CRA tool in Indigenous communities by training non-dental primary care providers to perform CRA. Our team is also hoping to report on the feedback obtained from focus group participants (Table 2), which shaped the tool's development and layout.

As previously mentioned, CRA tools are not without limitations. Only a handful are validated,[52-54] some of the combined factor questions are not evidence-based, and many are developed by expert panels rather than based on systematic reviews of the literature. Fortunately, there is growing recognition that CRA tools must be evaluated and validated. This is why our team first conducted the systematic review of the literature, undertook the environmental scan of existing CRA tools, focus group tested our drafted tool with end users in order to refine it, and are now undertaking a pilot validation study of this newly developed Canadian CRA tool for children <6 years of age.

Involving non-dental primary care providers in CRA can improve access to dental care for many children via referrals and is a sustainable option in communities having paucity of dental professionals. A recent systematic review revealed that non-dental providers can successfully perform CRA to control ECC.[55] Another recent systematic review indicated that CRA tools for preschoolers have good accuracy and strongly endorsed and recommended the practice of CRA despite there being a limited number of prospective trials to validate CRA tools.[56]

Few Canadian children benefit from early dental visits, which increases the risk for ECC, particularly in low socioeconomic areas.[57,58] Those dwelling in rural and remote regions are less likely to receive early first initial examinations.[59-61] Promising ways to improve early childhood oral health include CRA, promoting first visits by the first birthday and establishing dental homes.[62,63] Early adoption of preventive oral health routines sets the foundation for a lifetime of optimal dental health, and earlier visits contribute to better dental outcomes, less restorative and emergency care, more prevention, and lower treatment costs.[57,64-66] Engaging primary care providers in early childhood oral health promotion and CRA is needed to address ECC in Indigenous communities.

Although CRA and preventive oral health care delivered by non-dental primary care providers are new in Canada,[67-69] there are good lessons on integration from the United States.[70-81] Several studies show that primary care providers are willing and can successfully provide preventive oral health services (CRA, counselling, fluoride varnish, diammine silver fluoride) to children facing access to care challenges and that this can reduce the need for treatment under general anaesthesia and resulting dental costs.[55,72,73,79-86] A recent Canadian study revealed that primary care providers in Indigenous communities are willing to incorporate preventive oral care into their clinics,[68] aligning with American Academy of Pediatrics and CPS recommendations to work interprofessionally to address ECC.[87,88]

5 | CONCLUSION

This review identified factors significantly associated with caries onset in preschool children over time, which informed the development of a CRA tool for young children in Canada

for use by primary care professionals, including non-dental providers. Although it is important to have such a tool for screening purposes, there is considerable utility in developing a complementary tool for use by dental professionals. This tool has the potential to improve access to oral health assessments and interprofessional collaboration in the area of young children's oral health.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

RJS conceived the idea, collected the data, analysed the data, led the writing, critically revised the paper, and approved the final version. JR conducted the systematic literature searches, critically revised the paper, and approved the final version. MS, DD, DD, CD, CG, TK, and RS collected the data, critically revised the paper, and approved the final version.

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REFERENCES

1. Dye BA, Tan S, Smith V, et al. Trends in oral health status: United States, 1988–1994 and 1999–2004. *Vital Health Stat 11*. 2007;11(248):1-92.
2. El Tantawi M, Folayan MO, Mehaina M, et al. Prevalence and data availability of early childhood caries in 193 United Nations Countries, 2007–2017. *Am J Public Health*. 2018;108(8):1066-1072.
3. Tinanoff N, Baez RJ, Diaz Guillory C, et al. Early childhood caries epidemiology, aetiology, risk assessment, societal burden, management, education, and policy: global perspective. *Int J Paediatr Dent*. 2019;29(3):238-248.
4. Schroth RJ, Smith W. A review of repeat general anesthesia for pediatric dental surgery in Alberta, Canada. *Pediatr Dent*. 2007;29(6):480-487.
5. Canadian Institute for Health Information. *Treatment of Preventable Dental Cavities in Preschoolers: A Focus on Day Surgery Under General Anesthesia*. Ottawa: Canadian Institute for Health Information; 2013:1–34.
6. Schroth RJ, Pang JL, Levi JA, Martens PJ, Brownell MD. Trends in pediatric dental surgery for severe early childhood caries in Manitoba, Canada. *J Can Dent Assoc*. 2014;80:e65.
7. Fontana M, Young DA, Wolff MS. Evidence-based caries, risk assessment, and treatment. *Dent Clin North Am*. 2009;53(1):149-161.
8. Berg JH, Slayton RL. *Early Childhood Oral Health*. Ames, IA: Wiley-Blackwell; 2009.
9. American Academy of Pediatric Dentistry. Guideline on caries-risk assessment and management for infants, children, and adolescents. *Pediatr Dent*. 2013;35(5):E157.
10. Canadian Dental Association. *CDA Position on Early Childhood Caries*. Ottawa: Canadian Dental Association; 2010.
11. Twetman S, Fontana M, Featherstone JD. Risk assessment–can we achieve consensus? *Community Dent Oral Epidemiol*. 2013;41(1):e64-e70.
12. Gao X, Di Wu I, Lo ECM, et al. Validity of caries risk assessment programmes in preschool children. *J Dent*. 2013;41(9):787-795.
13. Slayton RL. Clinical decision-making for caries management in children: an update. *Pediatr Dent*. 2015;37(2):106-110.
14. Mejàre I, Axelsson S, Dahlén G, et al. Caries risk assessment. A systematic review. *Acta Odontol Scand*. 2014;72(2):81-91.
15. Tellez M, Gomez J, Pretty I, Ellwood R, Ismail A. Evidence on existing caries risk assessment systems: are they predictive of future caries? *Community Dent Oral Epidemiol*. 2013;41(1):67-78.
16. Zero D, Fontana M, Lennon ÁM. Clinical applications and outcomes of using indicators of risk in caries management. *J Dent Educ*. 2001;65(10):1126-1132.
17. Guyatt GH, Oxman AD, Schünemann HJ, Tugwell P, Knottnerus A. GRADE guidelines: a new series of articles in the Journal of Clinical Epidemiology. *J Clin Epidemiol*. 2011;64(4):380-382.
18. Hultquist AI, Bågesund M. Dentin caries risk indicators in 1-year-olds. A two year follow-up study. *Acta Odontol Scand*. 2016;74(8):613-619.
19. Pienihäkkinen K, Jokela J, Alanen P. Assessment of caries risk in preschool children. *Caries Res*. 2004;38(2):156-162.
20. Lin Y-T, Lin Y-TJ. Factors associated with the risk of caries development after comprehensive dental rehabilitation under general anesthesia. *J Dent Sci*. 2016;11(2):164-169.
21. Ji Y, Du X, Okazaki Y, et al. Risk behaviors and its association with caries activity and dental caries in Japanese children. *Pediatr Dent J*. 2006;16(1):91-95.
22. Schroth RJ, Lavelle C, Tate R, et al. Prenatal vitamin D and dental caries in infants. *Pediatrics*. 2014;133:e1277-84.
23. Wang SS, Zhang H, Si Y, Xu T. Analysis of forecasting indexes for dental caries in 3-to 6-year-old children. *Chin J Dent Res*. 2016;19(3):153-158.
24. Alaki SM, Burt BA, Garetz SL. Middle ear and respiratory infections in early childhood and their association with early childhood caries. *Pediatr Dent*. 2008;30(2):105-110.
25. Warren JJ, Weber-Gasparoni K, Marshall TA, et al. A longitudinal study of dental caries risk among very young low SES children. *Community Dent Oral Epidemiol*. 2009;37(2):116-122.
26. Yokomichi H, Tanaka T, Suzuki K, et al. Macrosomic neonates carry increased risk of dental caries in early childhood: findings from a cohort study, the Okinawa child health study, Japan. *PLoS One*. 2015;10(7):e0133872.
27. MacRitchie HM, Longbottom C, Robertson M, et al. Development of the Dundee Caries Risk Assessment Model (DCRAM)–risk model development using a novel application of CHAID analysis. *Community Dent Oral Epidemiol*. 2012;40(1):37-45.
28. Hong L, Levy S, Warren J, Broffitt B. Association between enamel hypoplasia and dental caries in primary second molars: a cohort study. *Caries Res*. 2009;43(5):345-353.
29. Wagner Y, Heinrich-Weltzien R. Evaluation of an interdisciplinary preventive programme for early childhood caries:

findings of a regional German birth cohort study. *Clin Oral Investig*. 2016;20(8):1943-1952.
30. Chankanka O, Cavanaugh JE, Levy SM, et al. Longitudinal associations between children's dental caries and risk factors. *J Public Health Dent*. 2011;71(4):289-300.
31. Gao X-L, Hsu C-Y, Xu Y, et al. Building caries risk assessment models for children. *J Dent Res*. 2010;89(6):637-643.
32. Bernabé E, MacRitchie H, Longbottom C, Pitts NB, Sabbah W. Birth weight, breastfeeding, maternal smoking and caries trajectories. *J Dent Res*. 2017;96(2):171-178.
33. Gao X, Hsu C-YS, Loh T, Hwarng B, Koh D. Role of microbiological factors in predicting early childhood caries. *Pediatr Dent*. 2014;36(4):348-354.
34. Leverett D, Adair S, Vaughan B, Proskin H, Moss M. Randomized clinical trial of the effect of prenatal fluoride supplements in preventing dental caries. *Caries Res*. 1997;31(3):174-179.
35. Wagner Y, Heinrich-Weltzien R. Evaluation of a regional German interdisciplinary oral health programme for children from birth to 5 years of age. *Clin Oral Invest*. 2017;21(1):225-235.
36. Ghazal T, Levy SM, Childers NK, et al. Factors associated with early childhood caries incidence among high caries-risk children. *Community Dent Oral Epidemiol*. 2015;43(4):366-374.
37. Correa-Faria P, Paixao-Goncalves S, Paiva SM, Pordeus IA. Incidence of dental caries in primary dentition and risk factors: a longitudinal study. *Braz Oral Res*. 2016;30(1). https://doi.org/10.1590/1807-3107BOR-2016.vol30.0059
38. Abanto J, Celiberti P, Braga MM, et al. Effectiveness of a preventive program based on caries risk assessment and recall intervals on the incidence and regression of initial caries lesions in children. *Int J Paediatr Dent*. 2015;25(4):291-299.
39. Hallett KB, O'Rourke PK. Baseline dental plaque activity, mutans streptococci culture, and future caries experience in children. *Pediatr Dent*. 2013;35(7):523-528.
40. Skeie M, Raadal M, Strand G, Espelid I. Caries in primary teeth at 5 and 10 years of age: a longitudinal study. *Eur J Paediatr Dent*. 2004;5(4):194-202.
41. Peltzer K, Mongkolchati A, Satchaiyan G, Rajchagool S, Pimpak T. Sociobehavioral factors associated with caries increment: a longitudinal study from 24 to 36 months old children in Thailand. *Int J Environ Res Public Health*. 2014;11(10):10838-10850.
42. Canada Go Breastfeeding and Infant Nutrition. Canada: Government of Canada; 2014. https://www.canada.ca/en/public-health/services/health-promotion/childhood-adolescence/stages-childhood/infancy-birth-two-years/breastfeeding-infant-nutrition.html. Accessed January 1, 2019
43. WHO Organization. Infant and Young Child Feeding; 2018. https://www.who.int/en/news-room/fact-sheets/detail/infant-and-young-child-feeding. Accessed October 15, 2018.
44. Dabiri D, Eckert GJ, Li Y, et al. Diagnosing developmental defects of enamel: pilot study of online training and accuracy. *Pediatr Dent*. 2018;40(2):105-109.
45. Fan CC, Wang WH, Xu T, Zheng SG. Risk factors of early childhood caries (ECC) among children in Beijing - a prospective cohort study. *BMC Oral Health*. 2019;19(1):34.
46. Boustedt K, Roswall J, Twetman S, Dahlgren J. Influence of mode of delivery, family and nursing determinants on early childhood caries development: a prospective cohort study. *Acta Odontol Scand*. 2018;76(8):595-599.
47. Akinkugbe AA, Brickhouse TH, Nascimento MM, Slade GD. Prenatal smoking and the risk of early childhood caries: a prospective cohort study. *Prev Med Rep*. 2020;20:101201.
48. Boustedt K, Roswall J, Kjellberg E, Twetman S, Dahlgren J. A prospective study of perinatal and metabolic risk factors for early childhood caries. *Acta Paediatr*. 2020;109(11):2356-2361.
49. Boustedt K, Dahlgren J, Twetman S, Roswall J. Tooth brushing habits and prevalence of early childhood caries: a prospective cohort study. *Eur Arch Paediatr Dent*. 2020;21(1):155-159.
50. Schroth RJ, Rothney J, Sturym M, Dabiri D, Dabiri D, Dong C, Grant C, Kennedy T, Sihra R. A systematic review of evidence on caries risk assessment for preschool children and recommendations for the development of a Canadian caries risk assessment tool for screening purposes. Winnipeg, MB; 2017:98.
51. Schroth RS, Sturym M, Finch A, et al. *Caries Risk Assessment Project – Critical Appraisal and Revision/Refinement to Caries Risk Assessment Report and Focus Group and Pilot Testing of the Draft Caries Risk Assessment Tool*. Winnipeg, MB; 2018:35.
52. Agouropoulos A, Birpou E, Twetman S, Kavvadia K. Validation of three caries risk assessment tools for preschool children from areas with high caries prevalence. *Pediatr Dent*. 2019;41(5):391-399.
53. Chaffee BW, Featherstone JD, Gansky SA, Cheng J, Zhan L. Caries risk assessment item importance: risk designation and caries status in children under Age 6. *JDR Clin Trans Res*. 2016;1(2):131-142.
54. Chaffee BW, Featherstone JDB, Zhan L. Pediatric caries risk assessment as a predictor of caries outcomes. *Pediatr Dent*. 2017;39(3):219-232.
55. George A, Sousa MS, Kong AC, et al. Effectiveness of preventive dental programs offered to mothers by non-dental professionals to control early childhood dental caries: a review. *BMC Oral Health*. 2019;19(1):172.
56. Jorgensen MR, Twetman S. A systematic review of risk assessment tools for early childhood caries: is there evidence? *Eur Arch Paediatr Dent*. 2020;21(2):179-184.
57. Darmawikarta D, Chen Y, Carsley S, et al. Factors associated with dental care utilization in early childhood. *Pediatrics*. 2014;133(6):e1594-e1600.
58. Schroth RJ, Cheba V. Determining the prevalence and risk factors for early childhood caries in a community dental health clinic. *Pediatr Dent*. 2007;29(5):387-396.
59. Schroth RJ, Ndayisenga S, Guenther K, et al. Parents' perspectives on the Manitoba Dental Associaton's Free First Visit program. *J Public Health Dent*. 2016;76(3):206-212.
60. Schroth RJ, Guenther K, Ndayisenga S, et al. Dentists' perspectives on the Manitoba dental association's free first visit program. *J Can Dent Assoc*. 2015;81:f21.
61. Schroth RJ, Boparai G, Boparai M, et al. Tracking early visits to the dentist: a look at the first 3 years of the Manitoba Dental Association's free first visit program. *J Can Dent Assoc*. 2015;81:f8.
62. Canadian Dental Association. CDA Position on First Visit to the Dentist; 2012.
63. American Academy of Pediatrics Section on Oral Health. Maintaining and improving the oral health of young children. *Pediatrics*. 2014;134(6):1224-1229.
64. Savage MF, Lee JY, Kotch JB, Vann WF Jr. Early preventive dental visits: effects on subsequent utilization and costs. *Pediatrics*. 2004;114(4):e418-e423.
65. Lee JY, Bouwens TJ, Savage MF, Vann WF Jr. Examining the cost-effectiveness of early dental visits. *Pediatr Dent*. 2006;28(2):102-105.

66. Nowak AJ, Casamassimo PS, Scott J, Moulton R. Do early dental visits reduce treatment and treatment costs for children? *Pediatr Dent*. 2014;36(7):489-493.
67. Nicolae A, Levin L, Wong PD, et al. Identification of early childhood caries in primary care settings. *Paediatr Child Health*. 2018;23(2):111-115.
68. ElSalhy M, Gill M, Isaac DM, et al. Integrating preventive dental care into general Paediatric practice for Indigenous communities: paediatric residents' perceptions. *Int J Circumpolar Health*. 2019;78(1):1573162.
69. Shrivastava R, Couturier Y, Kadoch N, et al. Patients' perspectives on integrated oral healthcare in a northern Quebec Indigenous primary health care organisation: a qualitative study. *BMJ Open*. 2019;9(7):e030005.
70. Pierce KM, Rozier RG, Vann WF Jr. Accuracy of pediatric primary care providers' screening and referral for early childhood caries. *Pediatrics*. 2002;109(5):E82.
71. Long CM, Quinonez RB, Rozier RG, Kranz AM, Lee JY. Barriers to pediatricians' adherence to American Academy of Pediatrics oral health referral guidelines: North Carolina general dentists' opinions. *Pediatr Dent*. 2014;36(4):309-315.
72. Close K, Rozier RG, Zeldin LP, Gilbert AR. Barriers to the adoption and implementation of preventive dental services in primary medical care. *Pediatrics*. 2010;125(3):509-517.
73. dela Cruz GG, Rozier RG, Slade G. Dental screening and referral of young children by pediatric primary care providers. *Pediatrics*. 2004;114(5):e642-e652.
74. Pahel BT, Rozier RG, Stearns SC, Quinonez RB. Effectiveness of preventive dental treatments by physicians for young Medicaid enrollees. *Pediatrics*. 2011;127(3):e682-e689.
75. Quinonez RB, Kranz AM, Lewis CW, et al. Oral health opinions and practices of pediatricians: updated results from a national survey. *Acad Pediatr*. 2014;14(6):616-623.
76. Rozier RG, Slade GD, Zeldin LP, Wang H. Parents' satisfaction with preventive dental care for young children provided by nondental primary care providers. *Pediatr Dent*. 2005;27(4):313-322.
77. Rozier RG, Sutton BK, Bawden JW, et al. Prevention of early childhood caries in North Carolina medical practices: implications for research and practice. *J Dent Educ*. 2003;67(8):876-885.
78. Bader JD, Rozier RG, Lohr KN, Frame PS. Physicians' roles in preventing dental caries in preschool children: a summary of the evidence for the U.S. Preventive Services Task Force. *Am J Prev Med*. 2004;26(4):315-325.
79. Douglass JM, Clark MB. Integrating oral health into overall health care to prevent early childhood caries: need, evidence, and solutions. *Pediatr Dent*. 2015;37(3):266-274.
80. Holve S. An observational study of the association of fluoride varnish applied during well child visits and the prevention of early childhood caries in American Indian Children. *Matern Child Health J*. 2008;12(S1):64-67.
81. Meyer BD, Wang R, Steiner MJ, Preisser JS. The effect of physician oral health services on dental use and expenditures under general anesthesia. *JDR Clin Trans Res*. 2020;5:146-155.
82. Lewis C, Lynch H, Richardson L. Fluoride varnish use in primary care: what do providers think? *Pediatrics*. 2005;115(1):e69-e76.
83. Bernstein RS, Johnston B, Mackay K, Sanders J. Implementation of a primary care physician-led Cavity Clinic using silver diamine fluoride. *J Public Health Dent*. 2019;79(3):193-197.
84. Lewis CW, Boulter S, Keels MA, et al. Oral health and pediatricians: results of a national survey. *Acad Pediatr*. 2009;9(6):457-461.
85. Herndon JB, Tomar SL, Catalanotto FA, Vogel WB, Shenkman EA. The effect of Medicaid primary care provider reimbursement on access to early childhood caries preventive services. *Health Serv Res*. 2015;50:136-160.
86. Clark MB, Douglass AB, Maier R, et al.Smiles for Life: A National Oral Health Curriculum. Society of Teachers of Family Medicine 2010; 2019. www.smilesforlifeoralhealth.org. Accessed August 23, 2019
87. Irvine J, Holve S, Krol D, Schroth RJ. Policy statement - Early childhood caries in indigenous communities. *Paediatr Child Health*. 2011;16(6):351-357.
88. American Academy of Pediatrics, Committee on Native American Child Health, Canadian Paediatric Society, First Nations, Inuit and Métis Committee. Early childhood caries in indigenous communities. *Pediatrics*. 2011;127(6):1190-1198.
89. Yokomichi H, Tanaka T, Suzuki K, Akiyama T, Yamagata Z. Macrosomic neonates carry increased risk of dental caries in early childhood: findings from a cohort study, the Okinawa Child Health Study. *Japan. PLoS.One*. 2015;10(7):e0133872.

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