Pediatric Oral Health Research & Policy Center

Predictive Model for Caries Risk Based on Determinants of Health Available to Primary Care Providers

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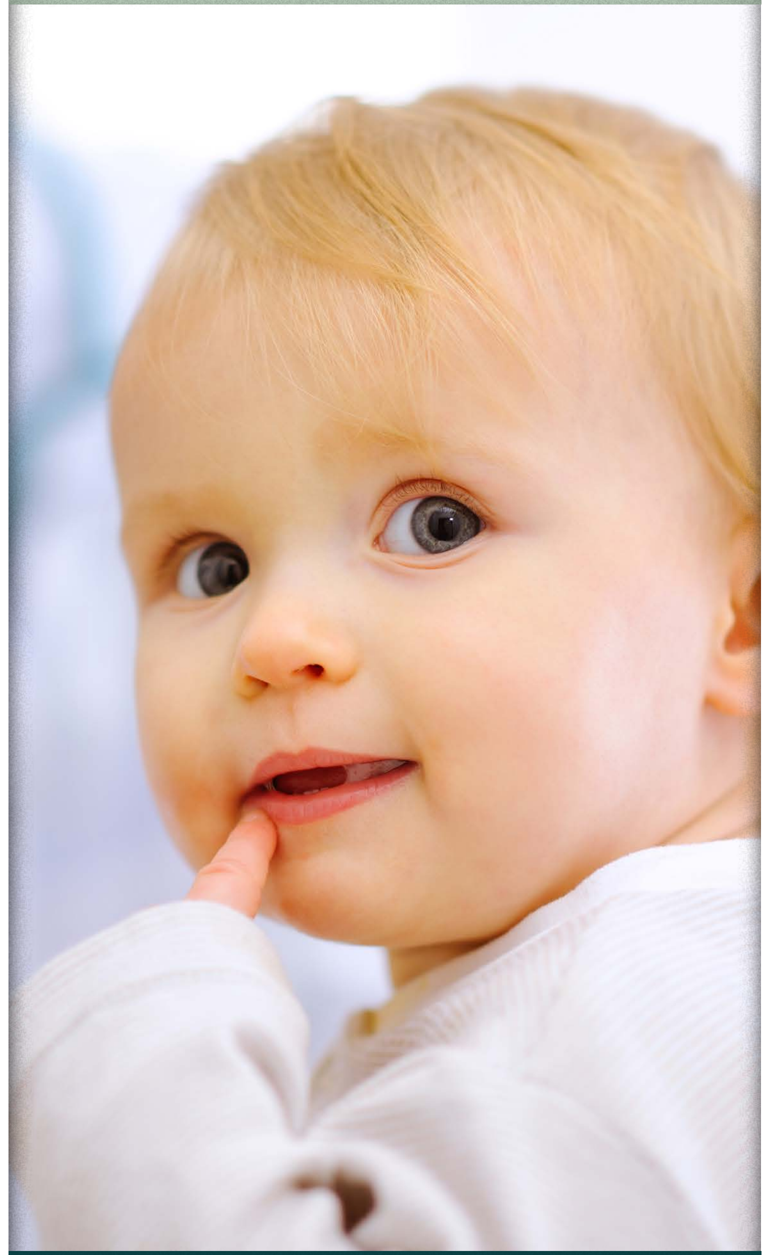

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Introduction

Dental caries in pediatric patients continues to be a serious health problem even though its prevalence has been reduced since 1960. Nevertheless, recent reports from the National Center for Health Statistics (NCHS) state that 23 percent of 2-5 year olds and 56 percent of 6-8 year olds experienced decay in their primary teeth. Twenty-one percent of children 6-11 years old experienced decay in their permanent teeth, increasing to 58 percent in adolescents.[1] Additionally, disparity in caries rates continues for some racial and ethnic groups and children from low income families in the United States.[1,2,3] In spite of the importance of oral health to overall health, most young children do not receive the benefits of an early dental visit at the time of the eruption of the first tooth and no later than 12 months of age, as recommended by the American Academy of Pediatric Dentistry (AAPD) and the American Academy of Pediatrics (AAP).

By the time many children have a dental visit, a majority of the behavioral and dietary risk factors for dental caries have been established, such as habits related to oral hygiene and sugar consumption. When the first dental visit is delayed, early childhood caries is often present, possibly necessitating extensive treatment with the risks associated with sedation or general anesthesia.[4,5] Primary care providers (PCP) have frequent contact with families and influence the oral health of young children by incorporating oral health prevention and early referral into their practices. For this reason, PCPs play a critical role in the prevention of dental caries and have a direct impact on the oral health status of young children.[6]

The goal of early identification of children who are at high risk for dental caries suggests the need for a Caries-Risk Assessment (CRA) tool that may be used by PCPs. Unfortunately, existing CRA tools, partially relying upon the presence of some level of dental disease for risk stratification, place the provider in the role of managing and controlling disease rather than preventing it. Our goal was to assess dental caries risk prior to the onset of dental disease.

In 2010, the United States Department of Human and Health Services released Healthy People 2020 goals and highlighted social determinants of health as one of the new goals. It defined social determinants of health as "conditions in the environments in which people are born, live, learn, work, play, worship, and age that affect a wide range of health, functioning, and quality-of-life outcomes and risks."[7] Instead of focusing only on conventionally defined areas of health, the study of social determinants explores additional factors that have an enormous impact on health and well-being.

Research supports a growing belief that common social and behavioral risk factors shape various seemingly unrelated, chronic health conditions. The World Health Organization states, "Oral disease prevention and the promotion of oral health needs to be integrated with chronic disease prevention and general health promotion as the risks to health are linked."[8] According to Shigan, "Controlling a small number of risk factors may have a major impact on a large number of diseases at a lower cost, greater efficiency and effectiveness than disease-specific approaches."[9]

This focus on public health approaches addressing social, environmental and cultural conditions is gaining even more attention after being addressed in the World Health Organization's Noncommunicable Disease 2020 Action plan.[10] Additionally, the common risk factor approach may be a more efficient solution to close health disparity gaps than investing resources in isolated approaches for oral health and other diseases.[11]

Beginning in 2014, the AAPD initiated a series of translational studies to explore pediatric medical providers' perceptions and practices surrounding oral health. The aim of this report is to summarize the results of Years 1 and 2 and report on a predictive model developed during Year 3 of the study.

Previous Studies

Year 1 Summary

Oral Health Integration in Primary Care

In Year 1, baseline data were gathered in focus groups and during practice observations with various primary care provider types and settings. Almost all pediatric providers considered oral health screening and education an integral part of children's overall health, yet providers' adoption of available caries-risk assessment tools was low due to competing time demands at well-child visits, limited clinical dental experience/education, and minimal reimbursement. These data indicated a need for a simple methodology to determine caries risk. Given the inconsistent use of existing tools, the limited amount of time during the well-child visit available for oral health, and increasing proof of the effects of social determinants of health, the logical next step in the investigation was to identify global variables collected routinely for all children seen in primary care visits that might show a predictive relationship with dental disease.[12]

Year 2 Summary

Nationwide Children's Hospital EHR/DHR Analyses

In Year 2, health screening measures already intrinsic to the well-child encounter were explored in order to create the basis for a new history-based, caries-risk screening tool that easily assimilates into the workflow of a well-child visit. A chart review was conducted to identify global, medical-specific factors that may correlate to caries risk at Nationwide Children's Hospital (NCH) in Columbus, Ohio. Since 2011, NCH has used an EpicCare Ambulatory EHR system (Epic Systems Corporation, Verona, Wis.) that fully integrates dental with general pediatrics and pediatric specialties.[13]

Methods

A listing of variables and diagnoses was generated, pertaining to nutrition, safety, development, demographics, complex medical disease, referrals to medical specialists, and other factors already embedded within the well-child examination templates that could be easily searched and extracted from the EHR.
This resulted in hundreds of identified variables. Given the overriding aim to produce a more simplified caries-risk assessment, this extensive list was further reduced quantitatively and qualitatively. Criteria for selection included frequency of provider entry, scientifically known or suspected caries associations, and consistency of appearance across both the 12- and 15-month well-child visit templates, resulting in a more manageable list of approximately 40 independent variables to be considered.

Univariate analyses were performed to determine the association between each medical variable and each of the two dental outcomes (Lifetime Caries Experience and Caries-Risk Status). For continuous variables, the comparisons were performed using Wilcoxon rank-sum test. For categorical variables, comparisons were performed using Pearson's chi-square test. All tests were two-sided at a significance level of *0.05*. Statistical analysis was performed using SAS Version 9.3. Univariate analyses compared each independent medical variable to the "Caries" versus "No Caries" groups, as well as the "High Risk" versus "Not High Risk" groups.

Results

In addition to well-known predictors of infants' caries risk, such as a history of nighttime feedings, family income level and the primary caregiver's oral health status, novel associations not previously included in other formalized caries-risk screeners and more specific to the medical encounter were preliminarily identified in Year 2. These predictors were delayed immunization status, prolonged breastfeeding beyond 12 months, early referral to a medical specialist and poor utilization of preventive medical care (Table 1).

Marshfield Clinic EHR/DHR Analyses

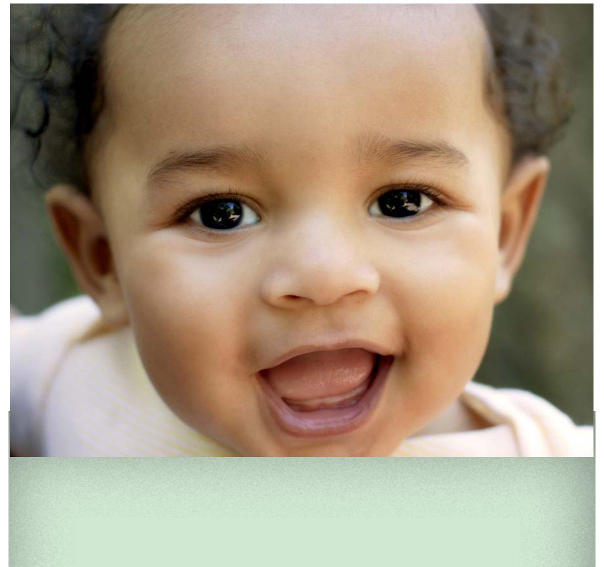
To further validate the significant variables identified in Year 2, as well as to increase and diversify the study population, patient data from a secondary testing site, Marshfield Clinic, were analyzed. Marshfield is a large multi-site community health and dental system based largely within central Wisconsin. With their semi-rural family (adults and children) patient population, this site was an ideal complement to NCH's mostly urban-based pediatric clients. Similar to NCH, Marshfield Clinic has an integrated medical and dental EHR system, necessary for this type of study.

Methods

Bivariate analyses were run to check for statistically significant associations between the potential predictor variables and the outcome variable. Chi-square tests were used for categorical variables, and the Wilcoxon rank-sum test was used for continuous variables, due to non-normal distributions. *P-values* less than *0.05* were considered statistically significant.

Results

Various predictors of lifetime caries experience were noted, including a history of broken appointments, speaking a language other than English, and older age at first dental visit (Table 1).



Year 3 Summary - Developing a Predictive Model

Purpose

The purpose of Year 3 was to develop a predictive model to characterize the likelihood that a child would have oral disease at the time of their first dental visit based upon information noted in the early well-child visits. Using extensive data from dental and medical records of subjects seen at both the NCH dental clinic and within the NCH primary care network, data collection was guided by the list of approximately 40 independent variables generated in Year 2. Both previously identified and new variables relevant to social and medical determinants of health were defined and validated.

The significant well-child variables were used to develop a predictive model to identify children who would have dental caries at the time of their first dental visit or a "High" value on the caries-risk assessment performed at their first dental visit.

Predictive models have been used in various clinical fields to predict the risk of an adverse outcome occurring, such as death following coronary revascularization or progression to chronic kidney failure. Using known correlates for an outcome, they provide a tool for providers to estimate clinical factors such as the anticipated rate of progression of a disease or risks in a specific population.

It should be noted that predictive models aid in identifying associations and the relative importance of large numbers of variables in producing the desired outcome. However, they do not imply a causal relationship. Examples of predictive models being developed or under consideration at NCH are listed in Table 2.

Table 1. Variables with Significant Associations with Caries Outcome

Nationwide Children's Hospital: Significant Variables using Lifetime Caries Experience as the Outcome Variable (n=1,736)	*P-value*	Marshfield: Significant Variables using Lifetime Caries Experience as the Outcome Variable (n=3,630)	*P-value*
History of broken appointments	*0.0007*	History or broken appointments	*<.0001*
Reports Hispanic ethnicity	*0.0338*	Reports Hispanic ethnicity	*0.001*
Referral to MD specialist at 12 months	*<.0001*	Use of an interpreter	*<.0001*
Immunizations not up to date at 15 months	*<.0001*	Speaks a language other than English	*<.0001*
Breast milk at 15 months	*0.0095*	Not brushing teeth multiple times per day	*<.0001*
		Fluoride treatment prescribed	*<.0001*
		Older age at first dental visit	*0.0012*
		Medicaid Insurance	*0.005*
		ICD-9 Code for Thrush	*0.01*
		Reports Asian Race	*0.03*
		Not sleeping through the night	*0.03*
		ICD-9 Code for Vomiting	*0.048*

Table 2. Predictive Models Being Developed/ Under Consideration at Nationwide Children's Hospital

To Predict:

- A hospital admission within one month
- An ED visit for asthma within two weeks
- Which patients will no-show for their scheduled clinic appointment
- Hospital average unit census for the next shift
- Inpatient clinical deterioration within 12 hours
- Onset of type 1 diabetes in children
- Onset of childhood depression
- Likelihood of successfully family engagement with care coordination efforts

Methods

For the development of the predictive model, subjects were included according to the following criteria:

1. Had their first NCH dental clinic visit between Oct. 11, 2011, and Sept. 14, 2016.
2. Age at the time of the first NCH dental clinic visit was between 1.5 and 4 years.
3. Had a 12-month well-child visit (WCV12) or a 15-month well-child visit (WCV15) or an 18-month well-child visit (WCV18) in the NCH clinic system.

Two binary dependent variables, *caries indicator* and *high risk indicator,* were extracted from the dental clinic records associated with the first dental clinic visit. As the name implies, the *caries indicator* variable indicated whether or not caries were already present at the time of the first dental clinic visit. The *high risk indicator* variable, on the other hand, indicated whether the subject was given a "High" score for the Caries-Risk Assessment (CRA) performed during the first dental clinic visit. (Other possible CRA scores were "Medium" and "Low.") Three senior hygienists at NCH examined all patients before a final check by a dentist (faculty or resident). High risk was based on presence of any evidence of disease upon clinical examination, including caries, enamel irregularities, cavitated or non-cavitated lesion(s) or restorations within past six months. Presence of any other risk factor was labeled medium risk, and no presence of disease or other risk factors was labeled low risk. For example, a child who had no existing caries and no restorations in the past six months, but had a high frequency of carbohydrate intake, was marked as medium risk (Tables 3 and 4).

Table 3. NCH Baby Dental Clinic Caries-Risk Assessmentnt

Caries Risk Assignment (If existing caries are present, caries risk is High)	
Caries Risk Factors Include	(Existing carious lesions/non-cavitated white spots) (Existing restorations within the past 6 months) (High frequency carbohydrates) (Drinking water not fluoridated) (Not using fluoride toothpaste) (Heavy plaque or gingivitis) (Enamel defect) (Physical limitations or special needs) (Orthodontic appliance) (Other/comment)
Caries Risk Assignment	(Low) (Medium) (High)
Home Care Goals For Caregivers and Patients (caregiver or patient selects 1-2 goals they are willing to work on until the next visit)	
Home Care Goals	(Wean off bottle) (Wean off sippy cup) (Bedtime bottle/sippy) (Water in sippy cup) (Use fluoride toothpaste) (Drink fluoridated water) (Limit soda) (Juice and milk) (Limit sweets) (Daily flossing) (Use tartar control toothpaste) (Brush along gum line) (Mouth guard) (Sugarless gum) (Fluoride rinse) (No tobacco products) (Oral piercings) (Non-nutritive oral habits)

Table 4. NCH Oral Screening of Children at Risk (OSCAR) Form

Oral Screening of Children at Risk	
Does anyone clean/brush the child's mouth yet?	Yes/No
If yes, who?	Parent/Child/Both
How often are the teeth brushed?	Weekly/Most days/Once a day/Multiple times a day/NA
What time of day are the child's teeth brushed?	Morning/Afternoon/Bedtime/NA
Does the child cooperate with parental brushing?	Yes/No/Sometimes/NA
What type of toothpaste is used when brushing the child's teeth?	None/Fluoride/Non-Fluoride
Source of water	Tap water/Bottled water w/ fluoride/Bottled water without fluoride/Well/Reverse osmosis
Does the child drink at nap and/or night (includes nursing)?	Yes/No
Types of drinks at nap and/or night	Formula/Milk/Chocolate milk/Juice/Pop/Tea/Gatorade/Kool-Aid/Breastmilk/Other
Does the child use a bottle, sippy cup, regular cup with fluid other than water?	Yes/No
Types of drinks in bottle/sippy/regular cup	Formula/Milk/Chocolate milk/Juice/Pop/Tea/Gatorade/Kool-Aid/Other
Types of snacks?	Fruit/Starch/Dairy/Meats/Vegetables/Sugary/Other (comment)
Number of times a day child snacks	1-2/3-4/>4
Does the mother have active caries?	Yes/No/Other (comment)

In addition to the dependent variables extracted from dental records, a number of independent variables were extracted from the subject's medical records, collected during their 12, 15, or 18-month well-child visit. These variables were intended to serve as candidate risk factors (i.e., all risk factors that were given a chance to be included in the final predictive model) in predictive models for the two dependent variables.

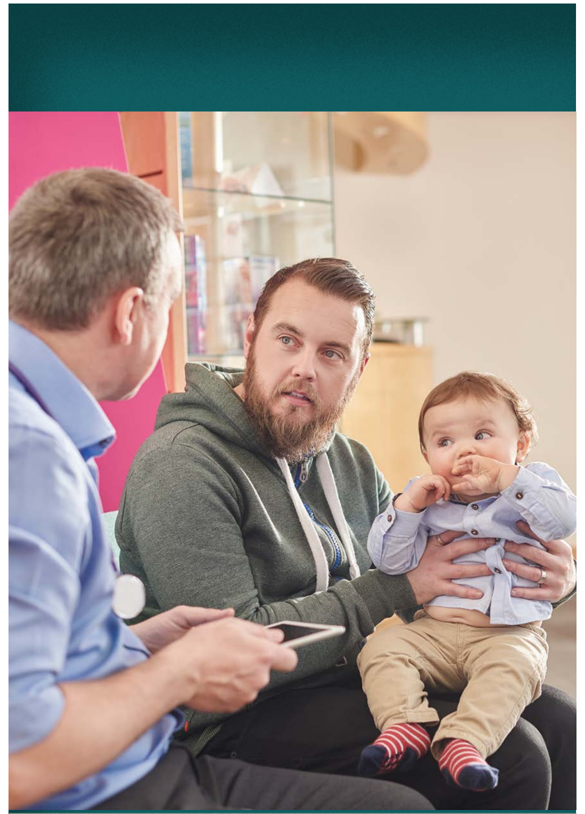
The final list of more than 60 extracted independent variables, their operational definitions and *P-values* can be found online at *http://www.aapd.org/assets/1/7/DentaQuest-RE-4-appendix.pdf* (Appendix A). The risk factors were organized into eight categories: demographics, developmental screening, dietary factors, sleep pattern, examination and history, financial and poverty information, lab reports, and parent/caregiver compliance measures. Risk factors except for Age At 1st Dental Visit are binary (0,1) in nature. For 12 of the risk factors, missing value indicator variables were created to identify those subjects in which it might be predictive that the basic data needed to assess the risk factor was missing. A binary "missing value indicator" (MVI) was included for the lead detected risk factor. For example, lead testing is routinely performed in the second year of life in association with a well-child exam. For this variable, the MVI was 1 if there was no blood lead value for the subject (i.e., the blood lead value is missing); otherwise, the MVI was 0. The *P-values* in Appendix A were generated by fitting a logistic regression model for the dependent variable with subject age, subject age squared, and the specified risk factor as independent variables. As such, the *P-values* indicate the statistical significance of the specified risk factor over and above a quadratic model involving only subject age.

Eight of the more than 60 independent variables are Natural Language Processing (NLP) variables. NLP allowed us to use computer programs to read and collect data from clinic notes. Those variables included developmental delay, high sugar diet, breastfeeding, nutrition ICD-9 codes, bottle/sippy cup use, nighttime feeding, sleep disturbance, and tooth examination. Several of these variables were extracted based on indicator words in the text and their numeric modifiers. For example, the high sugar diet variable was recorded as positive if the beverage or food type was considered an excessive sugar type and the usage amount mentioned in the note exceeded a specific threshold, such as "more than 16 ounces of whole milk a day." Unfortunately, many potential variables could not be extracted due to incomplete documentation in the EHR. A regular expression-based parser, a type of analytic formal grammar that goes over text to look for patterns, powered by a knowledge dictionary created by study domain experts, was used in the creation of the NLP variables.

Multiple logistic regression procedures were employed to develop a predictive model for each of the dependent variables, using SAS 9. 4 software and the LOGISTIC procedure. Each model was developed by starting with a full model of 72 independent variables and performing backward variable selection. The data were divided into a training set (70 percent) and a test set (30 percent) to develop the modeling approach. Models were developed with the training set and then applied to the test set in order to develop a method that would not over-train the model to the current data set. An over-trained model is one that appears to perform well when applied to the data used to develop it, but does not generalize well beyond the original data to new data sets.

As a result of the train and test exercises designed to avoid over-training, it was determined that the significance level necessary for a variable to stay in the model during backward selection would be set to *0.005*. (When conducting model variable selection from among a large list of candidate variables, it is often necessary to require that model variables be highly statistically significant in order to avoid developing a model that is over-trained to the data at hand and not generalizable to future data.) This method was then applied to the entire data set to produce the final predictive models.

The variables that remained in the model at the end of the backward selection process were statistically significant predictors that may be used to predict the dependent variable without fear that the model will be over-trained to the training data set. Some variables not included in the final model may be predictive of the dependent variable when examined on their own. However, they were not significantly predictive of the dependent variable over and above the variables included in the final model.



Results

For the development of the predictive data model, 2,009 subjects met the inclusion criteria for the study. Of the 2,009 subjects:

- 211 (10.5 percent) had dental caries at the time of their first dental clinic visit.
- 1,798 (89.5 percent) were caries free at the time of their first dental clinic visit.
- 570 (28.4 percent) had a Caries-Risk Assessment value of "High" at the time of their first dental clinic visit.
- 1,439 (71.6 percent) had a Caries-Risk Assessment value of "Medium" or "Low" at the time of their first dental clinic visit.

Age distribution can be found in Table 5. The data for these 2,009 subjects were employed to develop a predictive model for each of the dependent variables. For each model, the data comprised the dependent variable (*caries indicator* or *high risk indicator*), more than 60 independent variables, and AgeAt1stDental-Visit squared.

Age at first dental visit was a strong predictor of caries risk in both models, even in the presence of the risk factors included in the final models. As such, age at first visit accounted for a good portion of the predictive ability of the developed models, with "proportion with caries" and "proportion with high risk" increasing as age increased. So, as the child population became older, the proportion with caries and risk for caries increased (Figures 1 and 2).

Table 5. Age at First Dental Visit

Age in years	1.5 - 2.2	2.2 - 2.5	2.5 - 3.3	3.3 - 3.5	3.5 - 4
# of patients	460	542	448	364	195

Figure 1. Proportion with Caries by Age Category

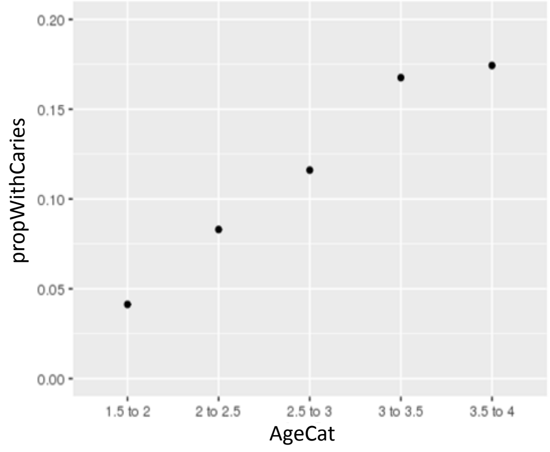
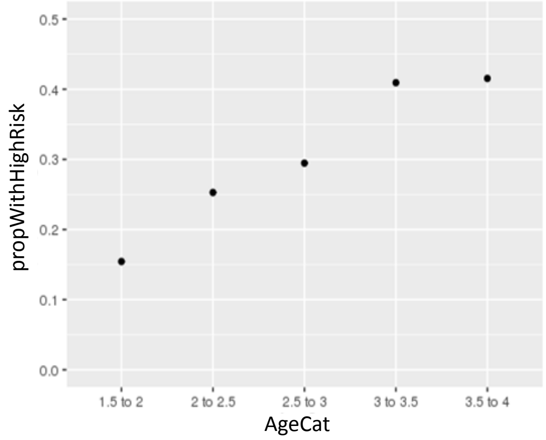


Figure 2. Proportion with High Risk by Age Category



High Risk Indicator Model

The predictive model for the *high risk indicator* dependent variable is documented in Table 6. The model produced a number on the interval 0 to 1, with values near 1 indicating that a child would be very likely to have a CRA of "High" at the time of her first visit to the dental clinic and values near 0 indicating a low likelihood of a "High" risk assessment. After backward selection, four risk factors were retained in the final High Risk Indicator model: age at first dental visit, breast feeding status, language spoken is not English, and no show percentage greater than 20 percent (AgeAtFirstDentalVisit, BreastFeedStatus, LanguageNotEnglish, NoShowPercGT20).

Table 6. Independent Predictors Included in the High Risk Indicator Model

Predictor	Odds Ratio	95% Confidence Limits for Odds Ratio	Number of Patients (0/1/Missing)
AgeAtFirstDentalVisit	2.11	(1.80, 2.47)	2009
BreastFeedStatus	2.47	(1.79, 3.40)	1793/192/24
LanguageNotEnglish	1.62	(1.31, 2.01)	1158/851/0
NoShowPercGT20	1.68	(1.31, 2.15)	1538/470/1

Table 7. Odds Ratio of "High" Caries Risk Assessment at First Dental Visit

Year(s) of Increased Age	Odds Ratio of Caries at First Dental Visit
1 year	2.11
2 years	4.45
3 years	9.39
4 years	19.82

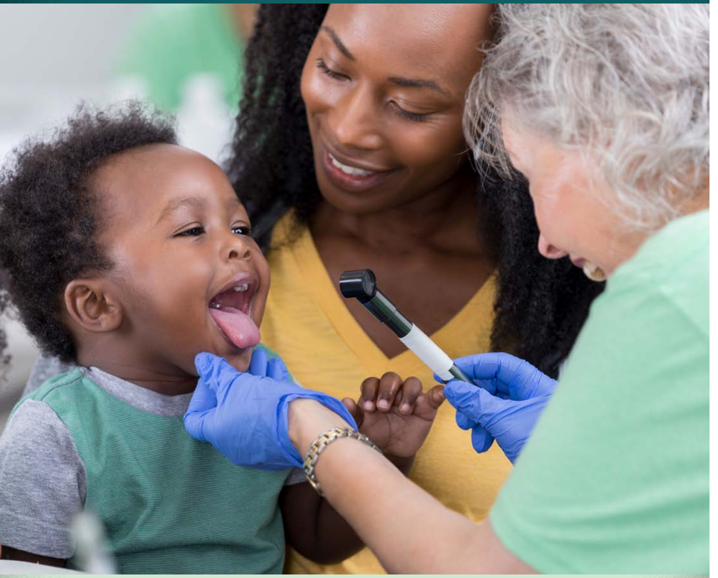
The predictive model indicated that the odds of a "High" CRA at the first dental visit increased by a multiplicative factor of 2.11 for every year of increased age. So, a child whose first dental visit was at 5 years of age would have 19.82 times the odds of having a "High" caries-risk assignment at their first dental visit compared to a child whose first dental visit was at 1 year of age (i.e., 4 years of increased age) (Table 7). A child whose medical record indicated breast feeding had 2.5 times the odds of having a "High" CRA at their first dental visit compared to a child whose medical record did not reflect being breast fed. A child whose primary language was not English had 1.6 times the odds of having a "High" caries-risk assignment at their first dental visit compared to a child whose primary language was English. A child who missed more than 20 percent of all scheduled appointments had 1.7 times the odds of having a "High" caries-risk assignment at the first dental visit compared to a child who did not miss more than 20 percent of all scheduled appointments (Table 6).

Table 8. High Risk Indicator Model Predictions by Age

Category	Breast Feed Status	No Show Perc GT20	Lang Not Eng	Study Population Percentages		Prob (High Risk)				
					Age	1.5	2	2.5	3	4
1	0	0	0	35.99		9.92%	13.78%	18.83%	25.20%	41.53%
2	0	0	1	32.11		15.14%	20.57%	27.33%	35.32%	53.51%
3	0	1	0	18.72		15.61%	21.17%	28.05%	36.14%	54.40%
4	1	0	0	3.63		21.34%	28.26%	36.39%	45.37%	63.64%
5	0	1	1	2.39		23.06%	30.32%	38.72%	47.84%	65.91%
6	1	0	1	6.12		30.55%	38.97%	48.11%	57.37%	73.94%
7	1	1	0	0.55		31.31%	39.83%	49.00%	58.25%	74.62%
8	1	1	1	0.50		42.49%	51.75%	60.90%	69.34%	82.66%

The selected probabilities produced by the high risk indicator model are reported in Table 8 to provide a more intuitive feel for how the model operates. The rows in Table 6 represent all possible combinations of the risk factors included in the model except for subject age. The values in the "Study Population Percentages" column indicate what percentage of the study population falls into each of the eight categories. The last four columns contain predicted probabilities that a subject will receive a "High" CRA at their first dental visit at five specific ages: 1.5, 2, 2.5, 3 and 4 years.

For example, a 4-year-old with no other risk factors has roughly the same probability of receiving a "High" CRA as an 18-month-old with all three risk factors. In this instance, the delay in a dental visit holds the same level of risk as the other factors combined.



Performance Measurement of the Predictive Models

In establishing a proper diagnostic test, it is difficult to find the correct threshold value that will differentiate a true positive and a true negative. If the threshold is too low, the test will be very sensitive, but specificity will be low, as many people will be included in the disease category that do not belong there (high number of false positives). If the threshold is too high, specificity will be high (few healthy people are included in the disease category), but sensitivity will be poor as many that truly have the disease will be left out. In order to detect the maximum number of patients who have the disease and to leave the maximum number of healthy patients out, the goal is to have a test in which sensitivity and specificity are both high.

The strongest models have high true positive rates corresponding to low false positive rates, and receiver operating characteristic (ROC) curves provide visual representations of these rates. The area under the ROC curve is commonly used to characterize the predictive strength of a model. Therefore, the closer the ROC curve is to the upper left-hand corner of the ROC plot, the stronger the predictive power of the corresponding model.

Predictive strength is often characterized by the area under the ROC curve, which is 100 percent for a perfectly predictive model and 50 percent for a model that does no better than a completely random prediction that has no diagnostic benefit. As the area under the ROC curve moves away from 50 percent and toward 100 percent, a model is judged to have stronger and stronger predictive power. Figure 3 illustrates what excellent, good, and no diagnostic benefit/worthless curves can look like.

Figure 3. Interpreting ROC Curves

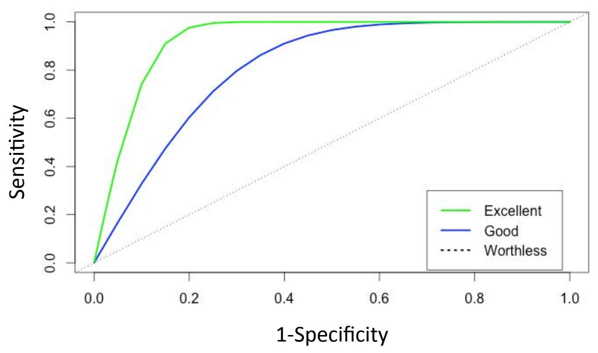
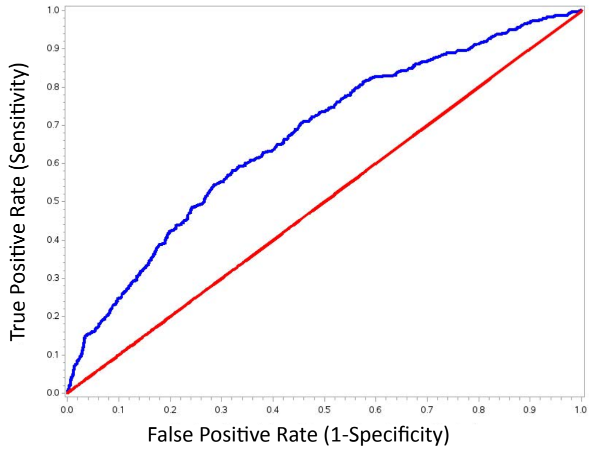


Figure 4. ROC Plot for High Risk Indicator Model



Performance Measurement of the High Risk Indicator Model

Figure 4 contains the ROC curve for the *high risk indicator* model. The blue curve characterizes the performance that may be expected if one used the *high risk indicator* model to refer children to the dental clinic by referring children with the largest model values. The curve characterizes the sensitivity and specificity of the model for various referral thresholds. The area under the ROC curve is 67 percent.

Figure 5 illustrates in more practical terms the expected performance of the *high risk indicator* model as a predictor of having a "High" CRA at their first dental visit. In this plot, the vertical axis represents the proportion of referred children that would actually have a "High" CRA at the time of their first dental clinic visit. The horizontal axis represents the proportion of the population that is brought into the dental clinic.

If this model was used to refer those at highest risk, or 10 percent of the population, for a higher level of primary care intervention and observation for early childhood caries and increased urgency of referral to a Dental Home, then approximately 53 percent of the referred children would actually have a "High" CRA on their first dental visit. This percentage compares to 28.4 percent of children who would have a "High" CRA on their first visit, if 100 percent of the population was referred or children were randomly referred to the dental clinic.

Additionally, we had access to a variable labeled "Tooth Problems". A child was flagged for this variable if providers annotated any of the following words in the medical chart: decay, abscess, white spots, cavities, plaque, red gums, and brown stains. Adding the Toothprob variable (Odds Ratio = 6.7) to our model increased the proportion with a "High" CRA on their first visit from 53 percent to 59 percent (Figure 5a).

Figure 5. Expected Performance of High Risk Indicator Model as a Referral Mechanism

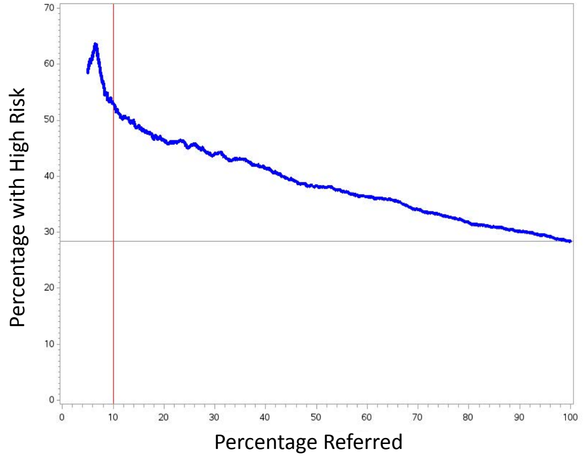
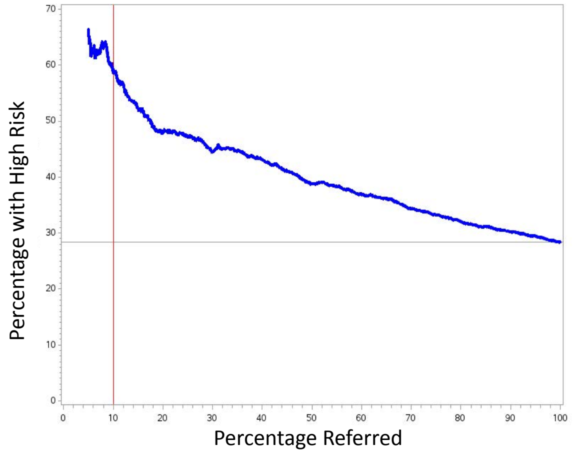


Figure 5a. Expected Performance of Alternate High Risk Indicator Model (including "Tooth Problems") as a Referral Mechanism



Caries Indicator Predictive Model

The predictive model for the *caries indicator* dependent variable is documented in Table 9. The model produced a number on the interval 0 to 1, with values near 1 indicating that a child would be very likely to have caries at the time of the first visit and values near 0 indicating a low likelihood of caries. After backward selection, three risk factors were retained in the Caries Indicator final model: age at first dental visit, language spoken is not English, and blood lead was not tested (AgeAt1stDentalVisit, LanguageNotEnglish, BloodLeadNotTested).

The predictive model indicated that the odds of caries at the first dental visit increased by a multiplicative factor of 2.1 for every year of increased age. So, a child whose first dental visit is at 5 years of age would have 19.45 times the odds of having caries at their first dental visit compared to a child whose first dental visit was at 1 year of age (i.e., 4 years of increased age) (Table 10). A child whose primary language was not English had 1.6 times the odds of having caries at their first dental visit compared to a child whose primary language is English. A child who did not have a blood lead test prior to 19 months of age had 2.25 times the odds of having caries at their first dental visit compared to a child who had a blood lead test prior to 19 months of age (Table 9).

Table 9. Independent Predictors Included in the Caries Indicator Model

Predictor	Odds Ratio	95% Confidence Limits for Odds Ratio	Number of Patients (0/1/Missing)
AgeAtFirstDentalVisit	2.10	(1.67, 2.64)	2009
LanguageNotEnglish	1.64	(1.23, 2.20)	1158/851/0
BloodLeadNotTested	2.25	(1.39, 3.66)	1892/117/0

Table 10. Odds Ratio of Caries at First Dental Visit

Year(s) of Increased Age	Odds Ratio of Caries at First Dental Visit
1 year	2.10
2 years	4.41
3 years	9.26
4 years	19.45

Performance Measurement of the Caries Indicator Model

Figure 6 contains the ROC curve for the *caries indicator* model. The blue curve characterizes the performance that may be expected if one used the *caries indicator* model to refer children to the dental clinic by referring children with the largest model values. The blue curve characterizes the sensitivity and specificity of the model for various referral thresholds. The area under the ROC curve is 67 percent.

Figure 7 illustrates in more practical terms the expected performance of the *caries indicator* model as a predictor of having dental caries at the first dental visit. In this plot, the vertical axis represents the proportion of referred children who would actually have dental caries at the time of their first dental clinic visit. The horizontal axis represents the proportion of the population that is brought into the dental clinic.

If this model were used to refer those at highest risk, 10 percent of the population, for a higher level of primary care intervention and observation for early childhood caries and increased urgency of referral to a Dental Home, then approximately 22 percent of the referred children would actually have dental caries on their first dental visit. This would compare to 10.5 percent of children who would have caries at their first dental visit if 100 percent of the population was referred or children were randomly referred to the dental clinic.

Figure 6. ROC Plot for Caries Indicator Model

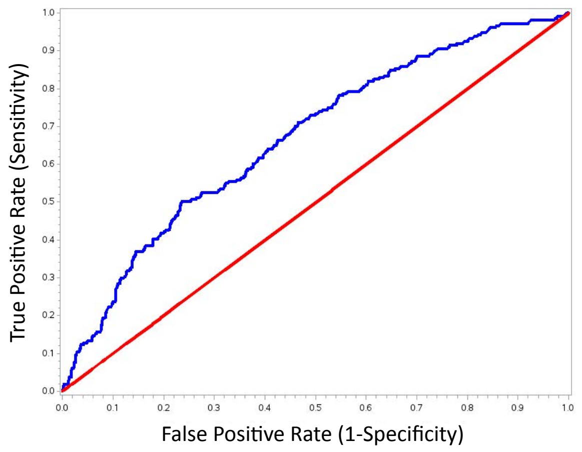
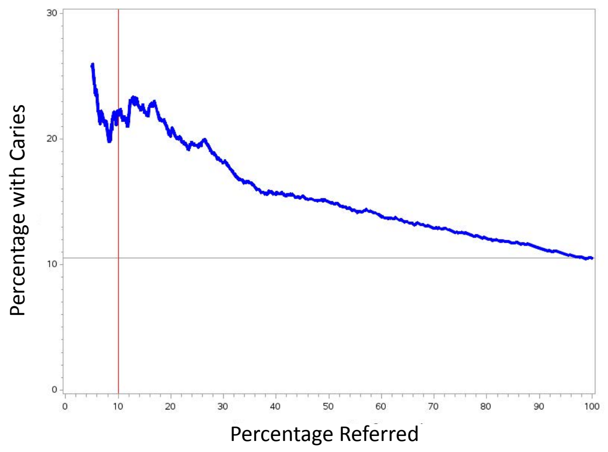
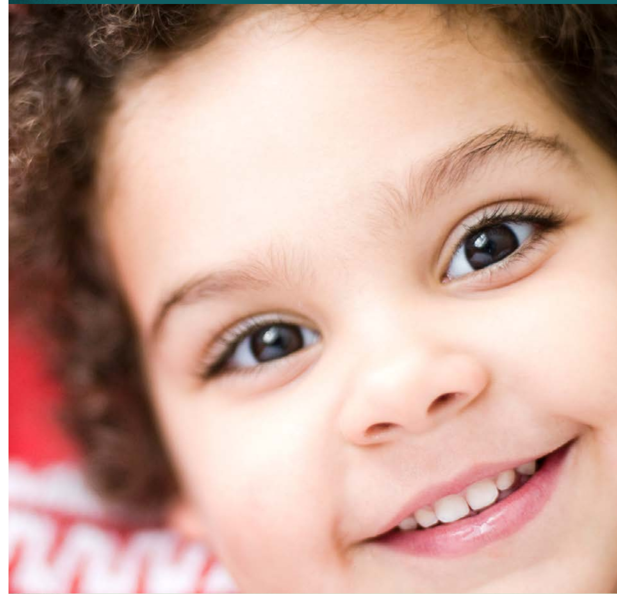


Figure 7. Expected Performance of Caries Indicator Model as a Referral Mechanism





Discussion

EHR variables accessible to primary care providers performing well-child exams allow the opportunity for enhanced education and referral of at-risk children who have not yet seen an oral health provider for routine preventive care. Our studies suggest that starting at the 18-month well-child visit, primary care providers can use five variables to assess the risk of future or present caries risk even if caries is not readily apparent on a well-child oral health exam. The five variables are:

- Age of the child
- History of a preventive dental health visit
- Duration of breastfeeding
- No-show rate (e.g. broken appointments, etc.)
- Preferred spoken language

A predictive model such as the one developed by our research allows primary care providers to identify children at low, moderate and high risk of future caries. Although the AAPD and AAP recommend referral to an oral health home early in life, many barriers presently exist to early access to an oral health home. This model identifies children needing a higher level of primary care intervention, observation for early childhood caries and increased urgency in obtaining a Dental Home.

This risk assessment model for primary care offers an alternative to current caries-risk assessment tools. No existing instrument can ensure accurate categorization of children by risk or predict future caries experience through its application in clinical practice.[14,15,16] Biological risk factors have been traditionally used to determine caries risk, creating an overdependence on their use without considering the non-biological factors. With the availability of EHR records, a child's health and family history can be monitored from birth. Using available data, primary care providers can review the caries-risk score at periodic well-child visits, and make clinical decisions regarding interventions and referrals that will impact present and future disease risk.

Table 11 is an example of one way this type of model could be adapted into practice workflow.

Two-year-old Leia comes in for a well-child visit. She was breast fed longer than 12 months, English is not her primary language, and she hasn't yet had her first dental visit. Leia would receive a score of 4, putting her in the "High" risk category. The primary care provider takes note of her status, provides additional anticipatory guidance and education on oral health, and sends the family to speak with the referral coordinator to assist in setting up a dental visit (Table 11).

Table 11. Referral Tool for High Risk Indicator Model

Risk Variable	Breastfed after 12 months	No-showed 20% of appointments 0-18 months	Language not English	First Dental visit less than 2 years of age	First dental visit at 2-2.5 years of age	First dental visit at 3 years of age	First dental visit at 4 years of age
Score	1	1	1	1	2	3	4

Actual Probability of Each Risk Classification (Refer to Table 8).	
Low (2 or less)	9.9% - 21.34%
Moderate (3)	20.57% - 36.39%
High (4 or more)	30.32% - 82.66%

Age

Our predictive model showed a strong correlation between age at first dental visit and the probability of either having caries or being at high risk for caries. Research has explored the causes of delayed first dental visits. In a study of parent, staff and dental perspectives on access to dental care for Head Start children in Ohio, Siegal et al.[17] conducted surveys on perspectives regarding late entry to dental care for a preschool population. Cost of care, lack of insurance, competing parental responsibilities, long wait times and distance to the dental office were cited as the most common reasons for children never seeing a dentist.[17]

Earlier visits initiate intervention, which can eliminate or reduce decay, as well as prevent emergency treatment.[18] Earlier visits can also decrease the number of procedures performed and cost of treatment.[19] With a strong emphasis on prevention, the early visit gives parents counseling on infant oral hygiene, fluoride therapies, and healthy nutrition, as well as information about oral habits and dental injury prevention, which can lend a protective effect with regard to the development of early childhood caries.[20, 21]

In a sample of preventive dental users in Medicaid, children at highest risk of dental disease benefited from a visit before 18 months of age, but children at low or medium risk could delay their first visit until 3 years of age without an effect on subsequent dental outcomes.[22] A caries-risk tool such as the one developed here could help providers identify children with the highest risk, those who would benefit the most from earlier and higher level interventions and observation. It could assist in creating the most efficient implementation of resource allocation and effort.

Our studies largely involved children from low SES situations who tend to experience higher levels of dental caries and from minority and immigrant groups.[1,2,3] We also noted a geometric increase in likelihood of dental caries in children in just a year or two from the well-child visit. Our results, taken together with other large studies, support the values and benefit of the Age One visit.

"Children who had their first preventive dental visit by age 1 were more likely to have subsequent preventive visits but were not more likely to have subsequent restorative or emergency visits. Those who had their first preventive visit at age 2 or 3 were more likely to have subsequent preventive, restorative, and emergency visits. The age at the first preventive dental visit had a significant positive effect on dentally related expenditures, with the average dentally-related costs being less for children who received earlier preventive care."

~ Paul S. Casamissimo, DDS, MS, Chief Policy Officer, AAPD

Breastfeeding Status

The odds of a "High" CRA increased by a factor of 2.5 if the patient was breast fed. Breastfeeding status was defined as any phrases indicating the subject was breast fed in any progress notes prior to 19 months. More than a decade of research and laboratory studies support the hypothesis that certain feeding habits (e.g., nocturnal feeding, ad libitum feeding) and the presence of other sugars in the oral cavity (e.g., carbohydrates and sugary foods and snacks) may be true cause of concern in regard to a relationship between breastfeeding and caries.

A 2007 study from the 1999–2002 National Health and Nutrition Examination Survey found no evidence to suggest that breastfeeding or its duration are independent risk factors for early childhood caries, severe early childhood caries, or decayed and filled surfaces on primary teeth.[23] However, while breast milk alone may not be,[24,25] ad libitum breastfeeding after the introduction of carbohydrates has been implicated in early childhood caries.[26, 27, 28] The risk of caries increases when sugars are ingested frequently (snacking) and remain in the mouth for extended periods, such as feeding at nap/sleep times.[29, 30, 31] This study suggests that health care providers register a heightened level of concern relative to early childhood caries when breastfeeding is reported.

This research should not be interpreted to discourage breast feeding in an effort to decrease caries or caries risk. Instead, the focus should be placed on limiting naturally sweetened and sugar-added beverages, regulating the habit of grazing (snacking and drinking all day, instead of during set meal times), and brushing after meals and bedtime nursing.

Language Not English

Our predictive model demonstrated the importance of identifying the language preference of the family in determining risk of early childhood caries. Based on logistic regression analysis, children from families that did not speak English had 1.6 times higher odds of dental caries on presentation to the dental clinic than the baseline population of primarily low-income children.

United States Census data from 2009-2013 reports show over sixty million Americans speak a language other than English.[32] Our findings support the literature showing increased rates of dental caries and reduced utilization of early childhood dental care in children of limited English proficiency (LEP) families.[33]

Families with limited English proficiency also report communication barriers with providers and decreased satisfaction with care.[34] Tiwari et al.[35] interviewed low-income Latino caretakers of children less than 6 years old and found that although the families interviewed were aware of most of the factors causing dental caries, in many cases this knowledge did not translate into positive oral health behaviors.
The majority of those interviewed were not satisfied with their dentist and felt that they were often judged negatively in the visit with their child. Caretakers further complained that there was inadequate time to understand and discuss the prevention of dental caries and that treatment decisions were often not discussed in detail. They also noted that it was very difficult to bring their children to the dentist because of lack of time, the temperament of some children, and the belief by their peers and family that it was not necessary to bring children to the dentist unless they were experiencing pain.[35, 36]

No Lead Test/NoShow Percentage

An elevated no-show percentage and the absence of a lead test being completed by 19 months may reflect barriers to the use of health services for at-risk families. Regular attendance at clinic visits and a venipuncture test for toddlers may require resources and resilience beyond the capacity of many stressed families. Studies by Scheppers et al.[37] and Gurol-Urganci et al.[38] have defined the characteristics of patients with missed appointments and inadequate use of health services.[37, 38] The complex issues relating to these behaviors include patient, provider and system factors that may be unrecognized by care providers without further exploration.

The correlation of incomplete use of health care resources with later oral health risk and disease is consistent with the conclusions of Tom et al.[39] They noted that missed well-child appointments and low continuity of care have been shown to be associated with an increased risk of hospitalization for 43,000 continuously-enrolled children in Hawaii.[39]

Study Limitations

Study limitations prompt careful interpretations of some of the findings. As in most empirical studies, the research presented here was limited by the measures used. Electronic health and dental record reviews present limitations in the generalizability of results, as well as varying degrees of incomplete data entry by users. We used outcome and independent variables that were most practical, based on available data fields. Our data analysis was cross-sectional in nature and assessed caries experience and caries-risk status at a specific point in time, the first dental clinic visit. As a result, only associations may be demonstrated, not causality. In addition, caries determination and caries-risk status was performed subjectively by a large number of professionals and intra-examiner calibration was not performed.

The extracted Natural Language Processing (NLP) variables are also subject to interpretation. All NLP variables were coded based on data from clinical notes with one of the three possible values: positive, negative and missing. Missing values were assigned when there was no clinical note text available for NLP processing. Negative values were assigned when clinical note text was available for NLP processing and the note text either indicated an explicit negative outcome for the variable (true negative) or contained no information about the variable (inferred negative). Positive values were assigned when clinical note text was available for NLP processing and the note text indicated an explicit positive outcome for the variable.

Data from subjects used to build the predictive models were from one university hospital in a Midwestern community. These subjects may not reflect the population of the United States, and the models have not been validated in independent populations. Thus, care should be taken in generalizing the findings to other child populations.

Conclusions

This study demonstrates that risk factors present in a child's medical record prior to the age of 19 months may be used to predict the presence of dental disease and/or of high caries risk at the time of the child's first dental visit. The developed predictive models may be used to refer children for a higher level of care and dental care based on information available in current medical records from well-child visits.

During the first year of this study we set out to gather best practice information from primary care sites with established oral health promotion programs. Through focus groups and practice observations, primary care providers overwhelming emphasized the importance a simplified caries-risk assessment tool, and Electronic Health Record integration.

For the busy primary care provider, an easy-to-use caries-risk assessment model based on general medical factors may facilitate a consistent integraion of oral health intervention into well-child visits. Based on our studies, we suggest that positive findings during the well-child visit can translate to a referral pathway with high positive results. If primary care providers use older age, breastfeeding status and compliance issues in well-child practice to access caries risk, we feel caries rate could be reduced.

Our findings also support research suggesting that dental caries initiation is parallel to other health maladies in its relationship to negative social risk factors. We encourage primary care health care providers to consider elevated caries risk and the likelihood of existing dental caries when engaging families with behaviors and health care seeking history suggestive of difficulties acquiring care or complying with professional advice.

With such a tool, primary care providers could administer caries-risk assessment as a part of the well-child visit without taking time from other equally important health concerns. Children referred to dental care as a result of having large predictive model values would be much more likely to have dental caries or high risk for dental caries at the time of their first visit to a dental clinic, thus offering valuable preventive services in a targeted, efficient and cost-effective manner.

The use of this type of risk modeling to predict childhood caries remains a relatively untested science and would need to be validated in multiple populations and medical settings. Additional information might enhance the predictive value of this model, such as improved documentation of risk factors such as sugar-sweetened beverage consumption, prematurity and breast milk consumption. Better quality overall data collection is imperative to maximizing EHR use and functionality for further research into common risk factors for a myriad of health issues, to include childhood oral health.

Next Steps

Building a predictive model is just the first step. Currently, a pilot study is being conducted at Nationwide Children's Hospital. Data from patients who visited the Baby Dental Clinic from January to October, 2017, are being analyzed to determine whether or not the predictive model's abilities hold true in a new study population. Because the model can be expressed and deployed in many ways, subject matter experts and the model developer must go through a process where the subject matter experts learn in detail what kinds of deployments the model can and cannot support while the model developer learns the details of how the subject matter experts would like to deploy the model. Together, they will arrive at a final model fit for deployment with a deployment strategy supported by intuitive arguments demonstrating the value of the model.

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