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

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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 56 percent in adolescents. Additionally, disparity in caries rates continues for some racial and ethnic groups and children from low income families in the United States. 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. 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. 

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." Instead of focusing 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." According to Stipanuk, "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." 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. 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.

Begining 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.

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methods were considered statistically significant. For categorical variables, comparisons were performed using Pearson's chi-square test. All tests were two-tailed and considered significant if the resulting P-value was less than 0.05.

Methods

A listing of variables and diagnoses was generated, pertaining to nutrition, safety, development, demographics, medical history of complex medical disease, referred to specialty care, and other factors already embedded within the well-child examination templates that could be easily searched and extracted from the EHR system. This resulted in hundreds of identified variables. Given the overwhelming amount of data needed to produce a more specific 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 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 two-tailed sample test. For categorical variables, the Wilcoxon rank-sum test was used for continuous variables, due to non-normal distributions. P-values were considered statistically significant if less than 0.05.

Results

Various predictors of lifetime caries experience were tested (Table 1). These included a history of broken appointments, speaking a language other than English, and older age at first dental visit. All variables were significant at less than 0.05.

Table 1. Variables with Significant Associations with Caries Outcome

<table>
<thead>
<tr>
<th>Variable (n=1,736)</th>
<th>P-value</th>
<th>Variable (n=1,736)</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>History of broken appointments</td>
<td>0.0007</td>
<td>History or broken appointments</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>Breast milk at 15 months</td>
<td>0.0095</td>
<td>Referral to MD specialist at 12 months</td>
<td>0.0007</td>
</tr>
<tr>
<td>Reports Hispanic ethnicity</td>
<td>0.048</td>
<td>Use of an interpreter</td>
<td>0.005</td>
</tr>
<tr>
<td>Reports Asian Race</td>
<td>0.01</td>
<td>Inpatient clinical deterioration within 12 hours</td>
<td>0.01</td>
</tr>
<tr>
<td>Fluoride treatment prescribed</td>
<td>&lt;.0001</td>
<td>Inpatient clinical deterioration within 12 hours</td>
<td>0.01</td>
</tr>
<tr>
<td>Reportsnativity</td>
<td>0.0012</td>
<td>Inpatient clinical deterioration within 12 hours</td>
<td>0.01</td>
</tr>
<tr>
<td>Medicaid insurance</td>
<td>0.05</td>
<td>Hospital average unit census for the next shift</td>
<td>0.01</td>
</tr>
<tr>
<td>ICD-9 Code for Thorax</td>
<td>0.05</td>
<td>An ED visit for asthma within two weeks</td>
<td>0.01</td>
</tr>
<tr>
<td>Onset of childhood depression</td>
<td>0.048</td>
<td>Hospital average unit census for the next shift</td>
<td>0.01</td>
</tr>
</tbody>
</table>
| Inpatient clinical deterioration within 12 hours | 0.01 | Development of a predictive model

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. Long 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.
In addition to the dependent variables extracted from dental records, a number of additional variables were extracted from the subject's medical records, collected daily during the second year of life in association with a 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.

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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 with no recorded breast feeding. If a child primary language was not English and had 2.11 times the odds of having a “High” caries-risk assignment at their first dental visit compared to a child with a child whose primary language was English. A child who missed more than 20 percent of all scheduled appointments had 7.3 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).

The selected probabilities produced by the high risk indicator model are reported in Table 8 to provide a more intuitive line for how the model operates. The two “X’s” illustrate all possible combinations of the risk factors included in the model except for subject’s age.

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.

For the development of the predictive data model, 2,009 subjects met the inclusion criteria for the study. For the development of the predictive data model, the oral health status of the 2,009 subjects were employed to develop a predictive model for each of the dependent variables. For each subject, the data comprised the dependent variable (caries indicator or high risk indicator), more than 60 independent variables, and AgeAtFirstDentalVisit 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 high risk” increasing as age increased to 5 years.

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.

Results

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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.

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 55 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).

Performance Measurement of the Alternate High Risk Indicator Model

Figure 5a contains the expected performance of the alternate high-risk indicator model as a referral mechanism. 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 6. ROC Plot for Alternate High Risk Indicator Model Model as a Referral Mechanism

Figure 6a. Expected Performance of Alternate High Risk Indicator Model (including “Tooth Problems”) as a Referral Mechanism
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 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.

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 was 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

<table>
<thead>
<tr>
<th>Predictor</th>
<th>Odds Ratio</th>
<th>95% Confidence Limits for Odds Ratio</th>
<th>Number of Patients (0/1/Missing)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AgeAt1stDentalVisit</td>
<td>2.10</td>
<td>(1.67, 2.64)</td>
<td>2009</td>
</tr>
<tr>
<td>LanguageNotEnglish</td>
<td>1.64</td>
<td>(1.23, 2.20)</td>
<td>1158/851/0</td>
</tr>
<tr>
<td>BloodLeadNotTested</td>
<td>2.25</td>
<td>(1.39, 3.66)</td>
<td>1892/117/0</td>
</tr>
</tbody>
</table>

Table 10. Odds Ratios of Caries at First Dental Visit

<table>
<thead>
<tr>
<th>Year(s) of Increased Age</th>
<th>Odds Ratio of Caries at First Dental Visit</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 year</td>
<td>2.10</td>
</tr>
<tr>
<td>2 years</td>
<td>4.41</td>
</tr>
<tr>
<td>3 years</td>
<td>9.26</td>
</tr>
<tr>
<td>4 years</td>
<td>19.45</td>
</tr>
</tbody>
</table>

Table 9. Independent Predictors Included in the Caries Indicator Model

Performance Measurement of the Caries Indicator Model

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 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 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 primary care providers to identify children at low, moderate and high risk of future caries, even if caries is not readily apparent on a well-child oral health exam. The five variables are:

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

Biological risk factors have been traditionally used to determine caries risk, creating an overdependence on their use without considering the two 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>
<thead>
<tr>
<th>Risk Variable</th>
<th>No-show rate (e.g. broken appointments, etc.)</th>
<th>Duration of breastfeeding</th>
<th>Language not English</th>
<th>First dental visit before 12 months</th>
<th>First dental visit before 2 years of age</th>
<th>First dental visit before age of 3 years</th>
<th>First dental visit before age of 6 years</th>
</tr>
</thead>
<tbody>
<tr>
<td>Score</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
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Actual Probability of Each Risk Classification (Refer to Table 8). Low [0 or less]: 0.85% - 21.30% Moderate (1): 20.57% - 36.39% High [4 or more]: 30.32% - 82.66% Table 11. Referral Tool for High Risk Indicator Model

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 concept 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.12 Earlier visits initiate intervention, which can eliminate or reduce decay, as well as prevent emergency treatment.13 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.14,15

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.16 A caries-risk tool such as the one developed here could help primary care 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.16,17 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 and 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

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15
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. 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.

Language Not English

Our predictive model demonstrated the importance of identifying the language preference of the family in determining risk of early childhood caries.26, 27, 28 The risk of caries increased when sugars are ingested frequently (snacking) and that treatment decisions were often not discussed with their dentist and felt that they were often judged 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/No Show 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 children. Further exploration.

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.

No NLP variables are also subject to interpretation. All NLP variables were coded based on data from clinical notes. Missing values were assigned when there was no clinical note text available for NLP processing. Positive values were assigned when clinical note text was available for NLP processing and the note text either indicated an explicit positive outcome for the variable (true positive) 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.

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Pediatric Oral Health Research & Policy Center

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The study design that this report presents in a children’s medical record prior to the age of 19 months may be used to predict the presence of dental disease or high risk of caries at first visit to a dental clinic, thus offering valuable preventative services in a time-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 validated model. 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.

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 or high risk of caries at first visit to a dental clinic, thus offering valuable preventative services in a time-effective manner.

**Conclusions**

We compared the ease with which pediatric caregivers could access, deploy, and adapt the risk modeling model. Together, we will arrive at a final model fit for deployment with a deployment strategy.

**References**

The American Academy of Pediatric Dentistry (AAPD) is the recognized authority on children's oral health. As advocates for children's oral health, the AAPD promotes evidence-based policies and clinical guidelines; educates and informs policymakers, parents and guardians, and other health care professionals; fosters research; and provides continuing professional education for pediatric dentists and general dentists who treat children. Founded in 1947, the AAPD is a not-for-profit professional membership association representing the specialty of pediatric dentistry. Its 10,000 members provide primary care and comprehensive dental specialty treatments for infants, children, adolescents and individuals with special health care needs. For further information, please visit the AAPD website at http://www.aapd.org or the AAPD’s consumer website at http://www.mychildrensteeth.org.

The Pediatric Oral Health Research and Policy Center (POHRPC) exists to inform and advance research and policy development that will promote optimal children's oral health and care. To fulfill this mission, the POHRPC conducts and reports oral health policy research that advances children's oral health issues and supports AAPD public policy and public relations initiatives at the national, state, local, and international levels with legislatures, government agencies, professional associations, and other non-governmental organizations. For more information about the AAPD Pediatric Oral Health Research and Policy Center, please access our website at http://www.aapd.org/policycenter.

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