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ORIGINAL RESEARCH

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Associations between risk factors, including approximal contact types and dental caries in children from low-income families. Pilot study

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Abstract

The present cross-sectional study was conducted to evaluate various caries risk factors in children from low socio-economic groups and to assess if children with broad contacts between one or more primary molars (type I and S) should be categorized as at high caries risk. Clinical examinations were performed on 107, 3- to 10-year-old children from low socio-economic settings. Contact types along with other caries risk factors (insurance, diet, plaque, and fluoride use, and diet habits) were analyzed for effect on presence of caries lesions (prevalence) and caries experience (decayed, missing, filled teeth). 78% of the study population had dental caries lesions, with an average dmft of 5.6. Of the 277 evaluated contacts, 88% were categorized as broad contacts. Multivariate analyses failed to validate that broad contacts were a predictor of dental caries lesions. However, the analysis showed an association of insurance status, plaque index with dmft. In conclusion, the present study could not implicate broad contacts as a factor that increased caries risk in the studied population; however, it validates the importance of insurance status, plaque index, as well as diet frequency as predictors of dental caries lesions.

Keywords

Caries risk; OXIS contacts; Primary dentition

1. Introduction

Among factors that contribute to increased risk of dental caries, that is increased the risk of developing new caries lesions and/or progression of existing caries lesions in children include socio-economic conditions, diet, fluoride exposure, and oral hygiene habits [1]. Untreated carious lesions might lead to pain, and difficulties in chewing, talking, smiling and social roles [2]. Understanding the nature of caries as a disease and its risk factors can help build an appropriate patient-specific management plans based on their caries risk. Factors that increase an individual's caries risk operate at patient-level (for example, low socio-economic status, diet, oral hygiene) and at tooth-level, that is, they are site-dependent (for example, enamel defect, existing caries, contact types). Among site-dependent risk factors existing carious lesions and enamel defects have been strongly co-related with overall increased risk of developing new caries lesions in children [3].

The type of contact between the primary first and second molars has been evaluated as a caries risk factor in several studies [3–6]. The contact between primary molars can be of open (or not in contact) or closed nature. Closed contacts may predispose the child at high risk of caries [7]. Depending on the area of contact between the molars, the closed contacts can be viewed as point contacts or broad contacts. Kirthiga *et al.* [4] categorized the shape of approximal contact in primary teeth as open (O); X-shaped; I-shaped; and S-shaped (OXIS) respectively by assessing images of 28 children ages 3–14 year [4]. The X, I and S were used to describe closed contacts, that is, X as a point type of contact, and I and S as broad contacts of straight and curved nature respectively. Two studies by this research group evaluated the association of type of primary molar contact with risk of approximal caries and concluded that broad contact types (S and I) had higher chance of developing approximal decay compared to open (O) and point (X) contacts [5, 6]. From a clinician's perspective, it is important to know if a child presenting with one or more broad contacts should be categorized as high caries risk? A reasonable extrapolation of available research would implicate that as a site-dependent caries risk factor, broad contact types (S and I) would predispose the child to developing a carious lesion [5, 6]. Therefore, it would be of value to study if broad primary molar contacts put the child at an increased risk for developing caries lesions in presence of other established patient-level or tooth-level risk factors. The goal of this study was to investigate the association of primary molar approximal contact type and caries risk factors (such as insurance status, plaque levels, fluoride exposure, and dietary habits) with increased caries risk in children. The caries risk was determined by presence of dental carious lesions and caries

experience (dmft) in the primary dentition. The null hypothesis being tested is that there is no difference in caries risk among children from low socio-economic settings presenting with broad (types: S and I) versus point (type: X) primary molar contacts. A secondary analysis was to rank the frequently used caries risk factors for children from low socio-economic settings.

2. Materials and methods

2.1 Study design

This cross-sectional study adhered to the STROBE (Strengthening the Reporting of Observational Studies in Epidemiology) guidelines for reporting the findings [8]. Caregiver (parent/legal guardian) and child dyads who agreed to participate were sequentially recruited from a dental school clinic population comprised primarily of English or Spanish speaking, low socio-economic families. The study population comprised children from low socioeconomic backgrounds who presented for care at pediatric dentistry clinics, including those covered by public insurance (Medicaid) and those from low-income families without dental insurance. The research procedures, discomforts, risks as well as benefits were fully explained, and informed consent and HIPAA (Health Insurance Portability and Accountability Act) forms were obtained from the caregivers prior to beginning the research procedures to provide information on data safety and security provisions for safeguarding medical information. Inclusion criteria included a convenience sample of healthy children ages 3–10 years that were able to cooperate with a dental examination. Caregivers were asked to fill out surveys that included health behaviors, such as tooth brushing, use of fluoride, and diet. Bilingual clinic staff or interpreter services was used to assist caregivers that did not have a working knowledge of the English language.

2.2 Data collection

The descriptive characteristics of the participants such as age, gender, insurance status was recorded. Diet frequency, diet content and fluoride exposure were evaluated using an open ended eight questions questionnaire constructed based on Cariogram [9]. Diet frequency was scored as maximum three meal per day, maximum five meals per day, maximum seven meals per day, and more than seven meals per day. Diet content was documented as very low fermentable carbohydrate content, low fermentable carbohydrate content, moderate fermentable carbohydrate content, high fermentable carbohydrate content based on the scoring criteria and explanation used in Cariogram [9]. Fluoride exposure was documented as someone who receives maximum fluoride program (uses fluoride toothpaste plus constantly uses additional measures such as fluoride tablets or fluoride rinses and fluoride varnish), additional fluoride measures (uses fluoride toothpaste plus infrequently uses additional measures including fluoride tablets or fluoride rinses and fluoride varnish), fluoride toothpaste only, and someone who is receiving no fluoride exposure. One examiner performed the caries examination consisting of caries presence/absence and decayed, filled, and missing primary teeth (dmft). The comprehensive clinical examination was conducted in a dental clinic setting and radiographs were obtained when appropriate. Considering the challenges with diagnosing non-cavitated lesions, only cavitated lesions were included for analysis in this study. Plaque score was assessed by the Silness and Loe criteria [10]. Primary molar contacts were photographed with an intraoral camera (ProDENT Dental USB Intraoral Camera PD740, Orlando, FL, USA) and the photographs categorized contacts based on OXIS classification [4]. Intra-examiner calibration of OXIS contact categories was performed using previously published criteria [4]. A single examiner tested reliability of identifies contact type on intraoral photos of ten patients with 100% accuracy. The same examiner did the clinical examination and collected information regarding demographics, diet, and fluoride exposure from the parents.

2.3 Statistical analysis

The data was tabulated in Microsoft Excel Spreadsheet and the statistical analysis was carried out using GraphPad Prism Version 10, Boston, MA, USA. Univariate analyses were conducted to check the possible association of putative caries risk factors including broad molar contacts (primary outcome) with caries prevalence (present/absent) and caries experience (dmft), including analysis of variance for the continuous outcomes and chi square test for binary outcomes.

In addition, a machine learning model, RapidMiner Studio Version 10.1, Troy, MI, USA [11] also was used to identify the factors predictive of caries presence (yes/no) in the study population (secondary outcome). Only those attributes that were found significant in the multivariate analysis were selected to build the Decision Tree and Random Forest (ensemble technique) classification models. The selected models are known to perform well with a low sample size [12]. The adequacy of sample size was also confirmed by accuracy of the models. The sample size would be considered suitable if the accuracy was near 80% [13]. There were no missing attributes detected in the selected dataset. For the Random Forest approach, gain ratios were used as the splitting criterion during hyperparameter tuning. To train the models, the dataset was split in a 70:30 ratio, and data models were developed with and without pruning. The maximum depth of each tree was restricted to 10 with 100 trees being used in this Random Forest. For Decision Tree, gain ratio was used as the splitting criterion for a maximum depth of 10 with pruning.

3. Results

3.1 Descriptive characteristics

A total of 107 children (51 females, 56 males) ages 3–10 years old (mean age 6.2 years) who met the inclusion criteria and were included to evaluate effect of contact type and other caries risk factors (age, gender, diet, plaque, and fluoride) on caries in primary dentition. The study population comprised of children from a low socio-economic setting attending the University of Maryland School of Dentistry Pediatric Dentistry Clinics, having a caries prevalence of 78% and a mean dmft of 5.6. The children recorded as insured were receiving public insurance; those uninsured were not eligible for dental insurance due to

their undetermined immigrant status. The baseline caries risk of the study population was considered high.

As reported by the caregivers, all of the study population were receiving fluoride through toothpaste or additional fluoride measures. Most children reportedly were consuming five meals in a day; and most children had plaque scores of 1. Of the 277 (149 maxillary and 128 mandibular) contacts between the first and second primary molars, the majority (88%) were broad contacts (I, S) (Fig. 1). Additionally, there was a difference in distribution of types of contact between the mandibular and maxillary arches, with a greater percentage of I contacts in the mandible, and a greater percentage of S contacts in the maxilla. Due to presence of proximal carious lesions, 25 children had only one molar contact that could be included for evaluation during data collection (Table 1).

Of the 107 patients, 74 (69%) subjects presented with only one or same type of existing primary molar contacts (I: 47, S: 19, X: 7, O: 1). The remaining 33 (31%) children had two or more different types of contacts in their four quadrants. Children presenting with only one type of contact did not exhibit significant differences in dmft, which implied that different contact types were not significantly associated with caries experience in the study population.

3.2 Univariate analysis of risk factors

Based on the univariate analysis, insurance status was found to be significantly associated with presence of carious lesions. Out of the 49 patients who had Medicaid, 30 had caries present (61.22%) and out of 58 uninsured patients, 53 had caries present (91.38%). In the study population, children less than 5 years of age presented with significantly lower caries experience (dmft) compared to 6–10-year-old children. Plaque accumulation also was significantly associated with dmft (Table 2).

3.3 Multivariate analysis of risk factors

To determine the relationship of various caries risk factors with caries experience (dmft) in the study population, a multivariate analysis was conducted for children with closed molar contacts (X, I and S), with adjustments for all potential confounding factors. This analysis found that having no insurance, moderate plaque, and diet frequency were significant predictors of increased dmft, which was true for all the three analyzed contact types: X ($p \leq 0.05$), I ($p \leq 0.05$) and S ($p \leq 0.05$) (Table 3). However, there was no significant difference in caries experience between children with point contacts (X) and those with one or more broad contacts (I or S). Therefore, we were unable to reject the null hypothesis as the results did not show that children with one or more broad contacts could be implicated to be at an increased caries risk in the study population from low-income families.

3.4 Assessment of significant risk factors using machine learning models

To rank the predictors of caries presence (yes/no) that were proven to be significant in the study population, a supervised machine learning model was utilized evaluating insurance status, plaque score, and diet frequency as caries risk factors. Contact types were not included since most types were not found to be significant on multivariate analysis. With the Random Forest model, insurance status had the highest weight as a predictor for presence of caries in a child, followed by plaque index score, and the diet frequency score. Accuracy, which is the fraction of total observations that are predicted correctly by the model was 78.1%; Precision which estimates how many of the predicted positives are actual positive was 84.6%; and Recall, which estimates how many of the actual positives are predicted correctly was 88%. An accuracy of near 80% and absence of overfitting for both machine learning models confirms that the sample size is adequate to support the results (Table 4).

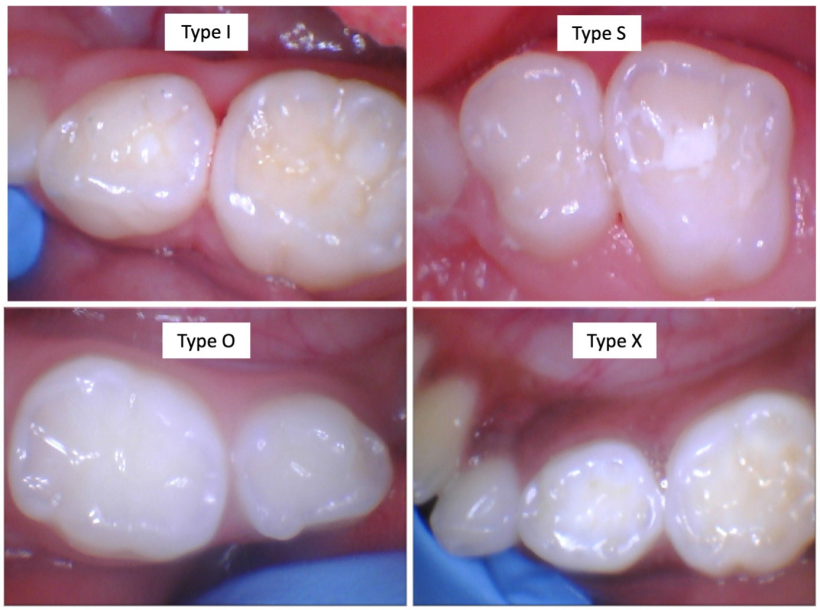

FIGURE 1. OXIS classification of contact. Type I and S were considered broad contacts.

TABLE 1. Cross-sectional descriptive characteristics of study population.

Subjects	N (%)
Number of children (#)	107
Mean age (standard deviation) (yr)	6.2 (1.98)
Gender	
Male	56 (52.34%)
Female	51 (47.66%)
Insurance	
% Insured	49 (45.79%)
% Uninsured	58 (54.21%)
Fluoride	
Score 3 (Avoiding)	0
Score 2 (Toothpaste only)	31 (28.71%)
Score 1 (Additional fluoride measures)	70 (65.42%)
Score 0 (Maximum fluoride program)	6 (5.61%)
Diet content (fermentable carbohydrates)	
Score 0 (very low)	2 (1.87%)
Score 1 (low)	47 (43.93%)
Score 2 (moderate)	41 (38.32%)
Score 3 (high)	17 (15.89%)
Diet frequency	
Score 0 (3 meals/day)	5 (4.67%)
Score 1 (5 meals/day)	94 (87.85%)
Score 2 (7 or more meals/day)	8 (7.48%)
Plaque score	
Score 0 (No plaque)	13 (1.50%)
Score 1 (Plaque not visible but detectable by wiping surface (Thin plaque))	82 (76.64%)
Score 2 (Visible (Moderate) plaque)	12 (11.21%)
Score 3 (Thick plaque)	0
Caries prevalence	78%
Caries experience (mean dmft)	5.6
Primary molar contacts	428
Number of unknown or missing contact types	151
Number of contacts scored	277
Contact types between 1st and 2nd molars	
O (open contact)	9 (3%)
X (point contact)	25 (9%)
I (broad contact)	168 (61%)
S (broad contact)	75 (27%)
Contact types between arches	
I contacts, mandible	55%
maxilla	45%
S contacts, mandible	21%
maxilla	79%

TABLE 2. Association of risk factors with caries presence, and caries experiences (dmft) in 107, 3–10 years old study population—Univariate analysis.

Factor	Category	N (%)	Caries present	*p* value	dmft Mean (SD)	*p* value
Insurance						
	Medicaid	49 (45.80%)	30 (36.14%)	<0.001*	4.7 (14.10)	0.03*
	Uninsured	58 (54.20%)	53 (63.86%)		5.1 (3.80)	
Age						
	<5 yr	44 (41.10%)	35 (42.17%)	0.68	5.1 (4.0)	0.03*
	>5 yr	63 (58.90%)	48 (57.83%)		6.0 (4.0)	
Gender						
	Female	51 (47.66%)	39 (46.99%)	0.80	5.43 (3.96)	0.62
	Male	56 (52.34%)	44 (53.01%)		5.82 (4.07)	
Plaque index						
	0	13 (12.15%)	7 (8.43%)		2.46 (3.02)	
	1	82 (76.64%)	65 (78.31%)	0.58	5.8 (3.92)	<0.001*
	2	12 (11.21%)	11 (13.25%)		7.92 (3.65)	
Fl_exposure						
	0	6 (5.61%)	4 (4.82%)		6.67 (4.27)	
	1	70 (65.42%)	54 (65.06%)	0.75	5.7 (4.13)	0.73
	2	31 (28.97%)	25 (30.12%)		5.29 (3.75)	
Diet frequency						
	0	5 (4.70%)	4 (4.82%)		4.6 (2.9)	
	1	94 (87.90%)	72 (86.75%)	0.77	5.6 (4.2)	0.44
	2	8 (7.5%)	7 (8.43%)		7.3 (2.2)	
Diet content						
	0	2 (87%)	2 (2.41%)		5.5 (0.7)	
	1	47 (44%)	36 (43.37%)	0.89	5.8 (4.5)	0.84
	2	41 (38%)	32 (38.55%)		5.7 (4.0)	
	3	17 (15.90%)	13 (15.66%)		4.8 (2.8)	

**Statistically significant. SD: Standard Deviation.*

Using a Decision Tree model, insurance status was considered the root node, that is, it was the considered the most important predictor for presence of caries in this study population (shown in Fig. 2). Other attributes associated with increased risk included higher diet frequency and plaque score. It is important to note that the Decision Tree model included only 75 datasets that corresponded to the included variables. However, there was high confidence supporting no insurance as a caries predictor, represented by over 50% of the dataset. Subjects with thin to moderate plaque accumulation represented over 30% of the dataset and could be interpreted to be a significant predictor of caries in children consuming five meals a day with high confidence. The test dataset performance metrics for both models showed 10% or less difference between training and test data implying that the models can achieve a generalized performance across Training and Testing data for similar populations (Table 4).

4. Discussion

The study population had high caries prevalence (78%) and caries experience (dmft 5.6), suggesting that the baseline caries risk of the study population was high. Caries-risk assessment models currently involve a combination of factors including previous caries, socio-economic conditions, diet, fluoride exposure, and oral hygiene habits [1]. With the ability to detect significant caries risk factors in its earliest stages health care providers can help prevent cavitation. Caries risk factors are variables that are thought to cause the disease directly (*e.g.*, microflora) or have been shown useful in predicting it

TABLE 3. Multivariate linear regression analysis by contact types I, S, X for caries experience (dmft) outcome in 107, 3–10-year-old children.

Factor	Difference in mean dmft (95% CI)	*p*-value
Multivariate model for contact type I, adjusting for potential confounders		
Insurance (Uninsured *vs.* Insured)	0.80 (0.05, 1.55)	0.04*
Age (Those over 5 *vs.* younger)	0.36 (−0.36, 1.09)	0.32
Plaque index 2 (*vs.* plaque index 0)	2.27 (0.66, 3.87)	0.01*
Plaque index 1 (*vs.* plaque index 0)	0.37 (−0.70, 1.45)	0.49
Fl exposure 1 (*vs.* Fl exposure 0)	−0.23 (−1.44, 0.98)	0.71
Fl exposure 2 (*vs.* Fl exposure 0)	−1.02 (−2.42, 0.39)	0.16
Diet frequency score 1 (*vs.* score 0)	1.30 (−1.99, 4.59)	0.44
Diet frequency score 2 (*vs.* score 0)	4.11 (0.01, 8.20)	0.05*
Contact I (*vs.* not contact I)	−0.17 (−1.73, 1.40)	0.83
Multivariate model for contact type S, adjusting for potential confounders		
Insurance (Uninsured *vs.* Insured)	0.80 (0.05, 1.55)	0.04*
Age (Those over 5 *vs.* younger)	0.37 (−0.34, 1.09)	0.31
Plaque index 2 (*vs.* plaque index 0)	2.29 (0.71, 3.88)	<0.001*
Plaque index 1 (*vs.* plaque index 0)	0.38 (−0.70, 1.46)	0.49
Fl exposure 1 (*vs.* FL exposure 0)	−0.25 (−1.47, 0.96)	0.68
Fl exposure 2 (*vs.* FL exposure 0)	−1.04 (−2.47, 0.39)	0.15
Diet frequency score 1 (*vs.* score 0)	1.38 (−1.89, 4.64)	0.41
Diet frequency score 2 (*vs.* score 0)	4.12 (0.02, 8.21)	0.05*
Contact S (*vs.* not contact S)	−0.06 (−1.49, 1.37)	0.93
Multivariate model for effect of contact type X, adjusting for potential confounders		
Insurance (Uninsured *vs.* Insured)	0.78 (0.03, 1.53)	0.04*
Age (Those over 5 *vs.* younger)	0.37 (−0.34, 1.08)	0.31
Plaque index 2 (*vs.* plaque index 0)	2.17 (0.58, 3.75)	0.01*
Plaque index 1 (*vs.* plaque index 0)	0.32 (−0.74, 1.39)	0.55
Fl exposure 1 (*vs.* Fl exposure 0)	−0.21 (−1.41, 0.98)	0.73
Fl exposure 2 (*vs.* Fl exposure 0)	−1.08 (−2.48, 0.31)	0.13
Diet frequency score 1 (*vs.* score 0)	1.54 (−1.69, 4.77)	0.35
Diet frequency score 2 (*vs.* score 0)	4.01 (−0.06, 8.07)	0.05*
Contact X (*vs.* not contact X)	−1.31 (−3.26, 0.65)	0.19

**Statistically significant. CI: Confidence Interval.*

TABLE 4. Performance metrics for evaluating accuracy, precision, and recall of training data versus test data using random forest and decision tree ML models.

Model	Train data accuracy	Test data accuracy	Train data class precision	Test data class precision	Train data class recall	Test data class recall
Random forest	81.3%	78.1%	81.4%	84.6%	98.3%	88%
Decision tree	78.7%	81.6%	79.2%	85.2%	98.3%	92%

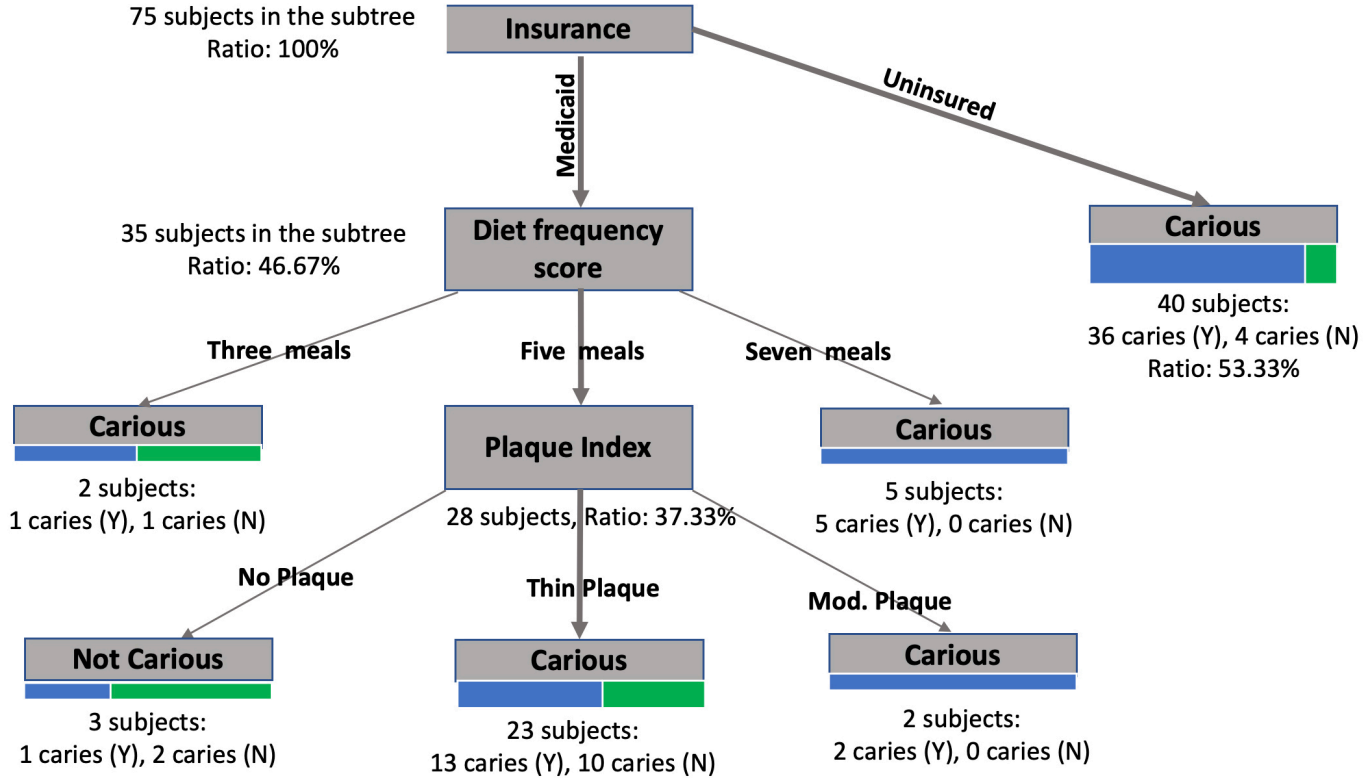

FIGURE 2. Decision tree: caries presence predictive model fitted for significant risk factors.

(*e.g.*, life-time poverty, low health literacy) and include those variables that may be considered protective factors. Currently, there is little information on the value of modifiable and non-modifiable caries risk assessment on children from low socioeconomic settings, and how tooth approximal morphology may impact the traditional caries risk factors in this population.

The findings from univariate analysis of 107 low socioeconomic children found that insurance coverage, child's age, and plaque score significantly were associated with caries presence and dmft. Insurance coverage was a key element to understanding the caries risk in this population with uninsured children having a caries prevalence of 91% versus 61% in the insured population, which suggests that the uninsured population had 30% more decayed teeth. Other studies have also reported that dental caries correlates with lack of dental insurance for the child [14–16]. There may be multiple reasons what there is higher caries prevalence and decayed teeth in uninsured children, such as lack of access to care, health care expectations, dietary differences, and other barriers to care for uninsured families that were not addressed in this current study.

Plaque index also was found to be significant in the present study, with moderate plaque (plaque index score 2) associated with dmft in this population. Studies of caries risk predictors in children have consistently reported that caries risk is associated with plaque scores [17]. The use of fluoride is well documented as a protective factor in caries prevention [1, 3]; however, it was not significantly associated with reduction of caries experience in the study population. This could be because the study population was high risk and did not report consistent use of maximum fluoride measures.

The predominant contact type in this population was categorized as I (61%) followed by S (27%), with S contacts identified primarily in maxilla, (79% compared to 21% in the mandible). However, distribution of contact types in the present study is markedly different from that reported from United Emirate's population (I contacts 33%; S contacts 6%), and an Indian population (I contacts 76%; S contacts 17%) [18]. The large variation of contact types in different populations may affect comparability between studies or generalizability of contact types as a risk factor.

Other OXIS studies have reported strong association of broad contacts (types S and I) with approximal caries [5, 6]. In the current study, the multivariate analysis of broad contacts (types I and S) was not a significant predictor of caries experience in this population, perhaps due to the uniformly high caries risk and prevalence in this study population and considering that most contact types observed were of the broad types.

The risk factors found significant on the multivariate analyses were analyzed further using machine language to help develop a predictive algorithm to identify significant risk factors that predispose a child to developing caries. Other reports of machine learning to predict early childhood caries found that the area under the curve at training and testing was above 0.70, and caries presence at baseline was the strongest predictor of new caries [19]. In the current study Random Forest model found that insurance status to be the most associated with dental caries lesions followed by plaque score, and diet frequency. The Decision Tree model confirmed that uninsured children were associated with increased risk of developing caries, irrespective of presence of other risk factors. For

children with insurance for dental care (Medicaid), increased caries risk was associated with high diet frequency; and for those children consuming about five meals per day, presence of plaque also was a good predictor for developing caries.

One strength of this study is the inclusion of multiple known caries risk factors, as well as contact types, to develop a better understanding of caries risk and experience in children of low-income families. The current study also utilized supervised machine learning to add to a predictive model for presence of caries. Both the Random Forest and Decision Tree models had high accuracy which supports generalizability of the results in similar populations, that is, children from low-income families.

Limitations of the present study include it having a small convenience sample from a low-income population that is likely to result in lower accuracy and generalizability especially for the different contact types and in different populations. There was only one examiner and the study also relied on parent responses to open-ended questions regarding diet and fluoride exposure, that relies on the care takers memory and possible biased responses.

From a clinical standpoint, the present study validates the importance of risk factors such as lack of insurance, diet frequency, and oral hygiene in determining the risk of developing new carious lesions. While approximal surfaces of molar with broad contacts have been known to have greater chance of developing carious lesions [5, 6], the present study could not substantiate the use of broad contacts as a predictor of high caries risk, reinforcing the need for further research such as prospective trials on a larger population from different socio-economic backgrounds.

5. Conclusions

1. In this pilot study of 107 children from families of low income, broad contacts (OXIS contact type I and S) were not associated with caries experience (dmft).

2. Insurance status, followed by diet frequency, and plaque levels were associated with caries experience.

3. Machine learning models also revealed that for insured children, diet frequency and plaque levels were associated with presence of caries lesions.

AVAILABILITY OF DATA AND MATERIALS

The data presented in this study are available on reasonable request from the corresponding author.

AUTHOR CONTRIBUTIONS

AJ—contributed to data acquisition, analysis, and manuscript preparation. KLH—contributed to data acquisition. VD and NT—contributed to the conception, design, analysis, and drafted and critically revised the manuscript.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

The study protocol was reviewed and approved by the University of University of Maryland Institutional Review Board (HP-00099013). A written informed consent was obtained from the parents in addition to verbal assent from the participating children.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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