

# Risk Assessment Criteria Applied to a Screening Exam: Implications for Improving the Efficiency of a Sealant Program

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## Abstract

**Objectives:** The present study aimed to determine the ability of first-grade screening exam findings to predict carious lesions in permanent first molars by fourth grade. The ability to identify high-risk children would be useful in the rational allocation of limited public health resources, such as the application of sealants.

**Methods:** Screening exams were performed on 204 children in 1st grade and 4th grade. Analyses were conducted at both the child- and molar- levels. Cross-tabulations were used to identify the threshold dmfs + DMFS in first grade that had the highest sensitivity and highest negative predictive value for discriminating between children with and without permanent caries (1) in the entire population and (2) in subpopulations defined by race/ethnicity, gender, and language spoken at home. This threshold then was entered into logistic regression models. **Results:** On the child and molar level, the study determined that dmfs + DMFS > 0 had the highest sensitivity (child: 69.4%, molar: 74.7%) and negative predictive value (child: 87.8%, molar: 94.4%). Using this test criterion, univariate logistic regression of the child-level data revealed an odds ratio of 2.72 ( $p=0.012$ ) for presence of permanent tooth caries experience. Controlling for gender, grade, race/ethnicity, and language spoken at home, the odds ratio increased slightly to 2.76 ( $p=0.012$ ). **Conclusions:** There is a relationship between carious lesion experience in 1st grade and carious lesion incidence in the first permanent molars by 4th grade. Using the dmfs + DMFS > 0 criterion may help public health providers determine which children should receive sealants when resources do not allow the delivery of sealants to all children.

**Key Words:** dental caries, sensitivity and specificity, public health dentistry, screening exam

## Introduction

To target a sealant program in a community with limited public funds, there is a need to be able to determine which preschool children are at high risk for developing decayed first permanent molars. Do carious lesions in 1st grade predict carious lesions in first permanent molars in 4th grade? To date, effective methods for caries prediction have remained elusive. A major limitation of these tests has been their reliance on single risk factors. Because carious lesions are the result of a multifactorial process, existing carious lesions, as a composite indicator of the etiologic risk factors for the disease, may be a better predictor of future risk.

Several studies have supported the existence of a positive relationship between caries experience and caries incidence (1-13). These findings are biologically plausible because this relationship reasonably may be attributed to developmental and genetic factors, a persistent environment (e.g., fluoride supplementation, *Streptococcus mutans*), or persistent habits. The ability of a screening exam to predict whom the high caries adolescents might be when they reach the 3rd or 4th grade level could assist in targeting prevention services for child populations, particularly the placement of sealants. The public health practitioner must consider that limited personnel are wasted if applied

indiscriminately. More efficient, rational allocation of time and effort would be confined to a limited number of children who, early in their caries-susceptible years, could be identified as members of the group at high risk for carious lesions. However, the application of a caries-experience screening exam to assess risk of future first permanent molar carious lesions requires that the strength of the relationship between caries experience and incidence be sufficient to discriminate between children at high risk and low risk of developing carious lesions.

Studies have examined the diagnostic performance of carious lesions in the primary teeth as predictors of carious lesions in the permanent teeth (4, 8, 10, 11), but a smaller number have focused on the more specific relationship between carious lesions experience and incidence of carious lesions in the first permanent molars (14, 15). The study by Raadal and colleagues is most directly methodologically comparable to the present study. These investigators found a significant, weak, negative correlation between dmft at age five and the number of intact permanent first molars at age eight. Using dmft>0 as the test criterion yielded a sensitivity of 80.0% and a specificity of 40.0% (14).

The investigation presented here addressed the following slightly different questions: Which threshold level of carious lesions in the 1st grade has the highest sensitivity and negative predictive value to predict experience of carious lesions in the first

permanent molars in 4<sup>th</sup> grade in US schoolchildren? How does this threshold perform in univariate regression and multivariate regression, controlling for ethnicity, gender, and language spoken at home?

### Methods

This study is part of an ongoing, longitudinal evaluation of the effectiveness of the Cambridge Public Health Department's Children's Dental Health Project. The Institutional Review Board of the Cambridge Health Alliance approved this study.

**Participants.** The study population was public schoolchildren who were in 1<sup>st</sup> grade in the 1997-1998 school year and 4<sup>th</sup> grade in 2000-2001 in Cambridge, Massachusetts, a fluoridated city. A passive parental consent model was used to maximize participation in the school-based screening exam. Additionally, the child must have been at school on the examination day assigned to his or her class, and the child must have been cooperative with the examination. Only children seen in both 1<sup>st</sup> and 4<sup>th</sup> grades were considered in the following analyses. Analyses were conducted on both the child- and molar-levels. For the purposes of the diagnostic performance analyses and logistic regressions on the child-level, children who had experienced carious lesions in their first permanent molars by 1<sup>st</sup> grade were excluded. For molar-level analyses, molars with decay or fillings by 1<sup>st</sup> grade were excluded from the analysis.

**Screening examination procedures.** The Cambridge public health dentist (CWD) and third-year dental students from the Harvard School of Dental Medicine conducted the screening examinations using a light, a dental mirror, and a tongue blade. All examiners had training and experience in conducting pediatric oral examinations and used the same standard definitions of classically observable caries as used in NHANES studies. Fillings and visually detectable carious lesions on the coronal, facial, lingual/palatal, and interproximal surfaces of the primary and permanent teeth were recorded using dmfs

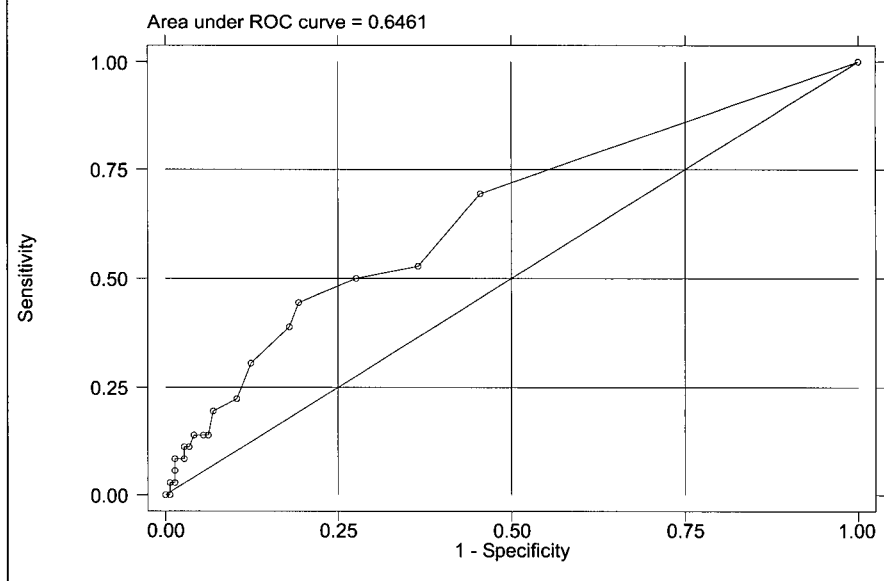
and DMFS indices, respectively. Teeth that were missing for reasons other than natural exfoliation also were recorded. If a child had untreated dental disease, his or her parents were notified and a follow-up was performed. The Children's Dental Coordinator (JL) took case management responsibility to obtain dental appointments for any children in need of immediate dental services. Approximately nine children per school required immediate attention.

Each child's race/ethnicity, gender, and the language primarily spoken at home were recorded. Race/ethnicity was categorized as white, black, Hispanic, Asian, or other, while language spoken at home was categorized as English or non-English.

**Statistical methods.** The analysis aimed to determine which threshold of dmfs + DMFS in first grade performed best in discriminating between children with and without carious lesion experience (decayed or filled surfaces) in their permanent first molars in fourth grade. The study then determined the performance of this threshold in subgroups of the population defined by gender, race/ethnicity, and language spoken at

home, respectively. Here, best performance was defined as that test with the highest sensitivity and the highest negative predictive value, as the authors wished to capture the maximum number of children who would develop carious lesions in their permanent first molars. The criterion for screening positivity was the presence of a threshold number of carious, filled, or missing (not due to natural exfoliation) surfaces. The sensitivity and specificity were calculated as  $\text{sensitivity} = a/(a+c)$  and  $\text{specificity} = d/(b+d)$ , where, a) number of children who met the threshold dmfs + DMFS and had carious lesion experience in their first permanent molars in 4<sup>th</sup> grade (true positives); b) number of children who met the threshold dmfs + DMFS but did not have carious lesion experience in their first permanent molars in 4<sup>th</sup> grade (false positives); c) number of children who were below the threshold dmfs + DMFS but had carious lesion experience in their first permanent molars in 4<sup>th</sup> grade (false negatives); d) number of children who were below the threshold dmfs + DMFS and did not have carious lesion experience in their first permanent molars in 4<sup>th</sup> grade (true negatives).

**FIGURE 1**  
The Receiver Operator Curve (ROC) for number of decayed or filled surfaces in first grade to predict first permanent molar decay experience by fourth grade



**TABLE 1A**  
**Relationship between thresholds of dmfs + DMFS in 1<sup>st</sup> grade and carious lesion experience in the 1<sup>st</sup> permanent molars in 4<sup>th</sup> grade**

Threshold*	Sensitivity (%)	Specificity (%)
dmfs+DMFS>0	69.4	54.5
dmfs+DMFS>1	50.0	64.8
dmfs+DMFS>2	47.2	73.1
dmfs+DMFS>3	38.9	80.7
dmfs+DMFS>4	36.1	82.1
dmfs+DMFS>5	30.6	88.3
dmfs+DMFS>6	22.2	90.3
dmfs+DMFS>7	19.4	93.1
dmfs+DMFS>8	13.9	94.5
dmfs+DMFS>9	13.9	95.2

\*Threshold number of dmfs + DMFS

**TABLE 1B**  
**Primary data for the relationship between dmfs + DMFS > 0 and carious lesion experience in the 1<sup>st</sup> permanent molars in 4<sup>th</sup> grade**

		D or F in 1 <sup>st</sup> Permanent Molars in 4 <sup>th</sup> Grade	
		Yes	No
dmfs + DMFS > 0 in 1 <sup>st</sup> grade	Yes	25	66
	No	11	79
		PVP = 27.5%	PVN = 87.8%

Sensitivity is the proportion of children who had carious lesion experience in the permanent first molars in 4<sup>th</sup> grade that could have been predicted on the basis of the presence of the threshold dmfs + DMFS at the screening exam in 1<sup>st</sup> grade. Specificity is the proportion of children who were caries-free in their permanent first molars in 4<sup>th</sup> grade that could have been predicted on the basis of being below the threshold dmfs + DMFS in 1<sup>st</sup> grade. Sensitivity and specificity have maximums of 1.

For the total population and the examined subgroups, the predictive value positive and the predictive value negative were calculated. The predictive value positive was interpreted as the proportion of children meeting the threshold dmfs + DMFS in 1<sup>st</sup> grade who were found also to have decayed or filled first permanent molars in 4<sup>th</sup> grade. The predictive value negative was interpreted as the fraction of children below the threshold dmfs + DMFS who were found not to have decayed or filled first permanent molars in 4<sup>th</sup> grade. Predictive value positive and negative have maximum values of 1. These values

were calculated as predictive value positive =  $a/(a + b)$  and predictive value negative =  $d/(c + d)$ , with a, b, c, and d as previously defined.

Logistic regression was performed on the child-level data to determine the strength of association between the threshold dmfs + DMFS in first grade that performed best and the presence decay or fillings in the first permanent molars in 4<sup>th</sup> grade, both on a univariate basis and when simultaneously controlling for race/ethnicity, gender, and language spoken at home. The simultaneous analysis of the effects of multiple covariates necessitated the use of modeling. Each of the covariates was treated as nominal categorical. The study also examined for multiplicative effect modification by sequentially entering cross product terms between the threshold dmfs + DMFS and ordinal categorical representations of sex, race/ethnicity, and language spoken at home, respectively. Those subjects with missing data were dropped from the logistic regression analyses. Finally, to facilitate comparison with previous studies, the study calculated Spearman's correlation coefficient

between the number of intact (sound or sealed) first permanent molars in fourth grade and first grade dmfs and dmfs + DMFS, respectively. All analyses were conducted using the STATA 6.0 (Stata Corp., College Station, Texas) statistical package, except the calculation of 95% confidence intervals for the sensitivities, specificities, predictive values positive, and predictive values negative, which were performed using Epi\_pak 1.0 (Centers for Disease Control, Atlanta, GA).

## Results

There were 204 children analyzed, of whom 11.3% had caries experience in their first permanent molars in 1<sup>st</sup> grade and 24.5% had caries experience in their first permanent molars by 4<sup>th</sup> grade. In grade one, the median dmfs was 1, with a range from 0 to 34. The median DMFS was 0, with a maximum of eight. The median dmfs + DMFS was 1, with a range of 0 to 34. The sample of children consisted of 53.4% girls, 46.6% boys, 48.0% black, 31.9% white, 15.7% Hispanic, 3.9% Asian, and 0.5% of a race/ethnicity not described by the other categories. Seventy-four and a half percent of these children reported that English was the main language spoken at home, and 25.5% reported that another language was primarily spoken at home (Spanish = 9.8%, Creole = 5.9%, Portuguese = 2.9%, other = 6.9%). The 23 children who already had experienced decay in the first permanent molars were dropped from the analysis. The remaining 181 children were 50.8% black, 30.9% white, 4.4% Asian, 13.2% Hispanic, and 0.6% other. Seventy-three and a half percent of these children spoke English at home, and 48.1% were boys.

There was a significant weak, negative correlation between the number of intact permanent first molars in 4<sup>th</sup> grade and 1<sup>st</sup> grade dmfs (Spearman's  $R = -0.19$ ,  $p = 0.01$ ) and dmfs + DMFS (Spearman's  $R = -0.22$ ,  $p = 0.003$ ), respectively. Table 1A shows the performance of the various thresholds of dmfs + DMFS in 1<sup>st</sup> grade in discriminating between those with and without decay or fillings in their first permanent molars in 4<sup>th</sup> grade. The area under the Receiver Operator

**TABLE 2**  
**Subgroup-specific performance of the dmfs + DMFS > 0 threshold**

Subgroup	Mean dmfs + DMFS (sd)	4th Grade Prevalence of D or F in 1 <sup>st</sup> Perm Molars	Sensitivity (95% CI)	Specificity (95% CI)	PVP (95% CI)	PVN (95% CI)
All (Crude)	2.75 (4.94)	19.9%	69.4% (51.7, 83.1)	54.5% (46.0, 62.7)	27.5% (18.9, 38.0)	87.8% (78.8, 93.4)
Gender						
Male	3.49 (5.95)	20.7%	66.7% (41.2, 85.6)	47.8% (35.8, 60.1)	25.0% (14.1, 39.9)	84.6% (68.8, 93.6)
Female	2.05 (3.68)	19.2%	72.2% (46.4, 89.3)	60.5% (48.6, 71.3)	30.2% (17.7, 46.3)	90.2% (77.8, 96.3)
Race/ethnicity						
Caucasian N = 56	2.50 (5.24)	17.9%	70.0% (35.4, 91.9)	58.7% (43.3, 72.7)	26.9% (12.4, 48.1)	90.0% (72.3, 97.4)
Black N = 92	2.91 (4.94)	21.7%	70.0% (49.9, 90.1)	54.2% (42.7, 65.7)	29.8% (17.8, 45.1)	86.7% (72.5, 94.5)
Hispanic N = 24	2.71 (4.89)	20.8%	80.0% (29.9, 99.0)	63.2% (38.6, 82.8)	26.9% (12.4, 48.1)	90.0% (72.3, 97.4)
Asian* N = 8	2.75 (3.88)	12.5%	0.0% -	14.3% -	0.0% -	50.0% -
Other* N = 1	2.0 -	100.0%	-	-	-	-
Language						
English	2.74 (5.16)	25.0%	66.7% (42.8, 93.3)	55.1% (35.7, 69.2)	34.6% (17.9, 55.6)	86.4% (64.0, 96.4)
Non-English	2.75 (4.31)	18.1%	75.0% (44.7, 83.6)	52.8% (45.2, 64.5)	24.6% (15.1, 37.1)	88.2% (77.6, 94.4)

\* None of the Asian children with carious first permanent molars had dmfs + DMFS > 0

\* Children who described their race/ethnicity as being other than Caucasian, Black, Hispanic, or Asian.

Characteristic (ROC) curve for dmfs + DMFS was 0.65 (Figure 1).

The sensitivity dropped and the specificity increased as the threshold was raised. The maximum sensitivity and predictive value negative were achieved by identifying children with any carious lesions in their primary or permanent dentitions (dmfs + DMFS > 0). Using this criterion, a sensitivity of 69.4% (95% CI: 54.4, 84.5) and a specificity of 54.5% (95% CI: 46.6, 62.6) were achieved. As children with any decay or fillings in their first permanent molars in 1<sup>st</sup> grade (N = 23) were dropped from consideration, the prevalence of decay experience in the first permanent molars in 4<sup>th</sup> grade was 19.9%, and the dmfs + DMFS > 0 threshold had a predictive value positive of 27.5% (95% CI: 18.3, 36.6) and a predictive value negative of 87.8% (95% CI: 81.0, 94.5). The tabular data from which these values were derived are shown in Table 1B. The performance of the dmfs+DMFS>0 in 1<sup>st</sup> grade threshold in subgroups of the population is shown in Table 2.

The same analyses were performed on the molar level data. The area under the ROC curve was 0.68. Again, dmfs + DMFS > 0 in 1<sup>st</sup> grade performed best, with a sensitivity of 74.7% and a specificity of 48.9%. Given that first molars that had experienced decay by 1<sup>st</sup> grade were dropped, the prevalence of decay or fillings in the remaining first molars in 4<sup>th</sup> grade was 10.2%. The predictive value positive thus was 14.2%, while the predictive value negative was 94.4%.

Because the dmfs + DMFS > 0 threshold performed best, this criterion was used within univariate and multivariate logistic regression models for the presence of decay or fillings in the first permanent molars in 4<sup>th</sup> grade. These analyses were conducted on the child-level data. The results of the constructed models can be found in Table 3.

Not controlling for any of the collected covariates, it was shown that the odds of having detected decay or fillings (i.e., caries experience) in the

permanent first molars in fourth grade in those with dmfs + DMFS > 0 in 1<sup>st</sup> grade is 2.72 (p=0.012) times the odds in those with dmfs + DMFS = 0. After controlling for gender, grade, race/ethnicity, and language spoken at home, the model revealed that the odds ratio increased slightly to 2.76 (p=0.012). This slight change indicates that there is unlikely to be confounding of the relationship between dmfs + DMFS in 1<sup>st</sup> grade and decayed or filled permanent first molars in 4<sup>th</sup> grade. None of the cross product terms between dmfs + DMFS > 0 and gender, race/ethnicity, or language spoken at home, respectively, was statistically significant when entered into the multivariate model.

### Discussion

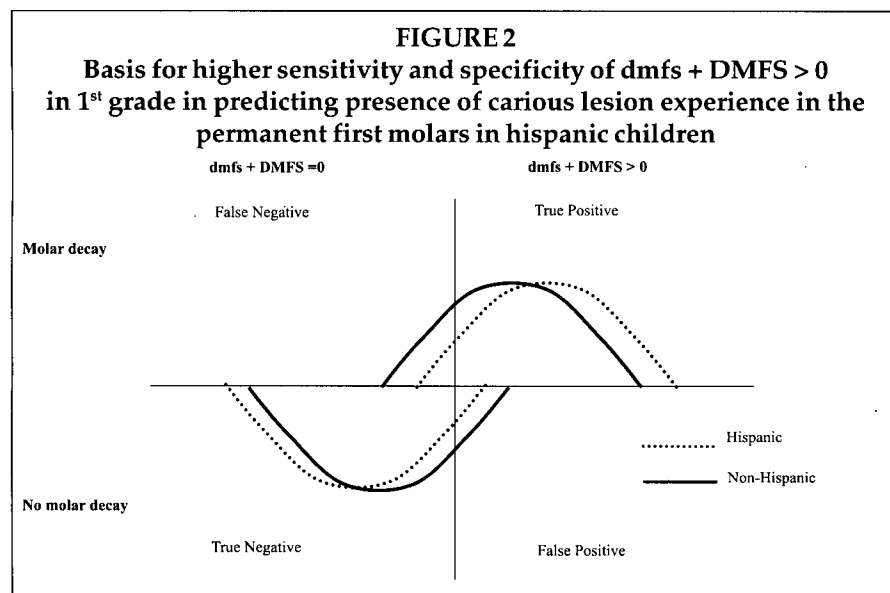
In aggregate, the findings of this study confirm that children with caries experience in 1<sup>st</sup> grade are at higher risk of having caries experience in their first permanent molars by 4<sup>th</sup> grade. The experience of one or more carious lesions by 1<sup>st</sup> grade (dmfs +

TABLE 3

**Results of logistic regression modeling the relationship between dmfs + DMFS > 0 in first grade and presence of decayed or filled permanent first molars in fourth grade, both univariate and adjusted for covariates.**

Model	Odds Ratio	Standard Error	p	95% CI
<b>Univariate</b>				
dmfs + DMFS score				
dmfs + DMFS=0	reference			
dmfs + DMFS>0*	2.72	1.08	0.012	1.24, 5.93
<b>Adjusted</b>				
dmfs score				
Dmfs+DMFS=0	reference			
dmfs+DMFS=1*	2.76	1.11	0.012	1.25, 6.10
<b>Sex</b>				
Male	reference			
Female	0.97	0.37	0.93	0.45, 2.06
<b>Race/ethnicity*</b>				
Black	reference			
White	0.84	0.37	0.70	0.35, 2.01
Asian	0.32	0.37	0.33	0.04, 3.05
Hispanic	0.82	0.50	0.74	0.25, 2.71
<b>Language</b>				
English	reference			
Non-English	-0.13	0.11	0.221	0.71, 1.08

\*Please note that the subject with race/ethnicity described as other was dropped due to insufficient sample size.



DMFS>0) was the test criterion that performed best in terms of predictive value negative and sensitivity in this diverse population of children. Thus, 69.4% of children who have had carious lesions in their first permanent molars by 4<sup>th</sup> grade had experienced decay by 1<sup>st</sup> grade; the molar-level analyses reveal that 74.7% of first permanent molars that had experienced decay by 4<sup>th</sup> grade came from children with dmfs + DMFS > 0 in 1<sup>st</sup> grade. Importantly, 85.9% of the children

identified to be free of carious lesion experience in 1<sup>st</sup> grade did not develop carious lesions in their first permanent molars by 4<sup>th</sup> grade, and 94.4% of first permanent molars from these children did not develop decay by 4<sup>th</sup> grade.

The performance of the criterion varied across subgroups (Table 2). It did not perform well in the Asian children. None of the Asian children with decay or fillings in their first permanent molars in 4<sup>th</sup> grade had dmfs +

DMFS > 0 in 1<sup>st</sup> grade, while 14.3% of the children without decay experience in their first permanent molars in 4<sup>th</sup> grade had dmfs + DMFS = 0 in 1<sup>st</sup> grade. This may have been due to a true difference in performance or to the lack of precision in the context of a small sample of Asian children. By contrast, the estimates of both the sensitivity and the specificity were higher in Hispanic children than in white, black, or Asian children. The altered performance may be attributed to the fact that Hispanic children who experienced carious lesions in their first molars had a higher mean dmfs + DMFS in 1<sup>st</sup> grade ( $5.4 \pm 8.4$ ) than the other racial groups, while the Hispanic children who did not experience these carious lesions had a lower mean dmfs + DMFS in 1<sup>st</sup> grade ( $2.0 \pm 5.5$ ) than the other racial groups (Figure 2).

Differences in the predictive values among subgroups can be accounted for by the variations in the sensitivity and specificity, as well as prevalence of detected carious lesions in the permanent first molars.

**Comparison with previous studies.** One challenge to the synthesis of this study's findings with those previously published is the range of study methods and conditions. The Raadal study is the most directly comparable (14). In the Raadal study the ability of caries prevalence in primary teeth (measured as dmft) at age six to predict fissure caries in permanent first molars at age nine was assessed. The correlation between dmft and the number of intact permanent first molars was -0.337 (Spearman's R,  $p < 0.01$ ); between the same outcome and dmfs, we found a correlation of -0.19 (Spearman's R,  $p = 0.01$ ). At the dmft > 0 threshold, the sensitivity was 80.0% and the specificity was 40.0%. To allow a more direct comparison with Raadal, this study also determined the ability of dmfs > 0 to predict carious lesion experience in the permanent first molars by fourth grade. A sensitivity of 63.9% and a specificity of 54.5% was achieved in this study. The differences between the studies may be attributed to the use of the dmfs index in this study and the fact that the Raadal study employed

bitewing radiographs and explorers to diagnose carious lesions.

This study was limited to 4<sup>th</sup> grade. Nevertheless, it can be speculated that over time, the dmfs + DMFS > 0 threshold would have a higher predictive value positive and a reduced predictive value negative. Thus, over time a greater number of the children at risk for carious lesions in the first permanent molars would be missed (as false negatives) than was apparent from this analysis.

**Implications for a sealant program.** To evaluate the screening criterion for the study, a hypothetical 1<sup>st</sup> grade sealant program in a population of 100 children will be considered. Considering only the children without carious lesion experience in their first molars in 1<sup>st</sup> grade, the prevalence of carious lesion experience in the first molars by in 4<sup>th</sup> grade was 19.9%. The children who did develop decay had a median of two decayed or filled first permanent molars. Using dmfs + DMFS > 0 as the threshold for sealant placement, the timely application of sealants could have prevented 69.4% of these children from developing carious lesions in their permanent first molars. It follows that 30.6% of the children who were going to develop carious lesions in their first permanent molars would have been missed. These estimates assume no interproximal decay and perfect protection by sealants. Further, 44.5% of children who would not have developed carious lesions in their first permanent molars would have had sealants placed unnecessarily. Expenditures were obtained from the Massachusetts Medicaid 2002 fee schedule. The reimbursement rate for placement of a sealant in a child was \$28.00, and for placement of a single-surface amalgam, it was \$63.00. Thus, it would cost \$11,200.00 to seal all first permanent molars in a population of 100 children. In the population represented by this study, 50.3% of the children had dmfs+DMFS>0. If only the teeth of the children meeting this threshold were sealed, the costs would be \$4,084.36 for unnecessarily sealed teeth, \$1,549.24 for appropriately sealed teeth, and \$1,527.98 for fillings in teeth that

should have been sealed. In total, this amounts to \$7,161.58, representing a savings of \$4,038.42 over the indiscriminant placement of sealants.

A limitation of the study is the potential for misclassification inherent to the visual caries detection method employed. As the authors of the study wished to assess the ability of carious lesions detected in a screening exam to predict carious lesions in the permanent first molars, there was a concern of under-estimating molar decay. If children both with and without dmfs + DMFS > 0 would be equally likely to have first permanent molar carious lesion experience under-estimated, the predictive value positive of the study would be downwardly biased, while the predictive value negative would be upwardly biased. An additional limitation is that, in the setting of a common outcome, the odds ratio overestimates the risk ratio.

In conclusion, the analyses presented here show that there is a relationship between caries experience in 1<sup>st</sup> grade and carious lesion incidence in the first permanent molars by 4<sup>th</sup> grade. There is some evidence that this relationship may vary across subpopulations. The utility of carious lesion experience in first grade as a predictor of risk for permanent first molar carious lesion incidence would depend upon the population and the resources of the public health program to which it would be applied. In the case of this study, the authors believe that risk assessment criteria applied to a screening exam have utility in assisting dental public health providers to determine which children should receive sealants when resources do not allow the delivery of sealants to all children.

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