Updated Comparison of the Caries Susceptibility of Various Morphological Types of Permanent Teeth

Mark D. Macek, DDS, DrPH; Eugenio D. Beltrán-Aguilar, DMD, MS, DrPH; Stuart A. Lockwood, DMD, MPH; Dolores M. Malvitz, DrPH

Abstract

In 1941, Klein and Palmer published a landmark study that ranked the relative susceptibility to dental caries of various morphological tooth types. Specifically, Klein and Palmer used a four-step approach, which included derivation of: (1) an eruption schedule; (2) posteruptive tooth age; (3) cumulative number of decayed, missing, and filled teeth and cumulative posteruptive tooth age; and (4) relative susceptibility values. Their study was conducted when dental caries prevalence and severity were generally high in the United States, prior to the introduction of preventive measures such as fluoride and dental sealants. This investigation used more recent data to assess whether declines in dental caries prevalence over time have been accompanied by changes in the relative susceptibility of permanent tooth types. ***Methods:*** *The data source for this investigation was the oral examination component of the Third National Health and Nutrition Examination Survey. This investigation used analytical methods to derive the relative susceptibility values that were identical with those used during the Klein and Palmer study. Full sample weights were used with SUDAAN so that the descriptive estimates would be representative of the US population. Analysis was limited to children aged 4 through 20 years.* ***Results:*** *The investigation found six categories of susceptibility, with molars being more susceptible than incisors, canines, or premolars. In general, susceptibility values declined since the Klein and Palmer study, providing additional evidence for a caries decline in the United States. First and second molar susceptibility values from the NHANES III data, however, intersected with those of Klein and Palmer, suggesting that factors specific to the molars, such as the selective use of dental sealants on these teeth, might be playing an additional role.* ***Conclusions:*** *Future research should explore factors that might explain the changes in relative susceptibility values over time. [J Public Health Dent 2003;63(3):174-82]*

Key Words: dental caries, children, health surveys, NHANES III, United States.

In 1941, Klein and Palmer (1) were the first to describe the relative susceptibility to dental caries of various morphological tooth types. Besides being the first of such studies, their investigation also was unique because the analysis accounted for differences in the length of time each tooth type was in the mouth before it succumbed to carious attack. In their study, Klein and Palmer found that the mandibular molars were most susceptible to carious attack, whereas the mandibular incisors and canines were least susceptible. This information was useful because it led policy makers and public health practitioners to focus attention on preventive and restorative measures that were tailored to these higher risk teeth.

When Klein and Palmer conducted their landmark investigation, the prevalence of dental caries was relatively high in the United States (2). Later in the century, however, a series of cross-sectional surveys (3-6) began to show declines in dental caries prevalence among children. Other studies showed that these declines were accompanied by changes in the character and distribution of disease (7), and severe disease was becoming concentrated in a smaller proportion of the child population (8,9).

Since the 1940s, a number of studies have described the relative susceptibility of teeth to carious attack (10-18); however, each of these studies has had some notable limitations. Most of the studies focused on the susceptibility of only tooth surfaces, all used relatively small target populations, and none replicated Klein and Palmer's original analytical methods.

The purpose of this investigation is to derive current relative susceptibility values for various morphological tooth types and compare these values with those derived from the original Klein and Palmer study. Unlike other studies that followed Klein and Palmer's landmark investigation, this investigation used tooth-specific data instead of tooth surface-specific data, a nationally representative sample, and Klein and Palmer's original analytical methods. The secondary purpose of this investigation was to determine whether the decline in dental caries prevalence in the United States has been accompanied by changes in relative susceptibility values for various morphological tooth types and to explore possible explanations for any changes that were observed.

Methods

Data Sources. This investigation used oral examination data from Phases I and II of the Third National Health and Nutrition Examination Survey (NHANES III) administered by the National Center for Health Statistics between 1988 and 1994. The oral

Send correspondence and reprint requests to Dr. Macek, Department of Oral Health Care Delivery, Baltimore College of Dental Surgery Dental School, University of Maryland, 666 West Baltimore Street, Room 3-E-02, Baltimore, MD 21201-1586. E-mail: mdm002@dental.umaryland.edu. Drs. Beltrán-Aguilar and Malvitz are at the Division of Oral Health, NCCDPHP, CDC. Dr. Lockwood is in the Division of Public Health, Georgia Department of Human Resources. During the writing of this manuscript, Dr. Lockwood was also with the Division of Oral Health, NCCDPHP, CDC. Manuscript received: 2/22/02; returned to authors for revision: 3/26/02; final version accepted for publication: 7/1/02.

examination component of the survey included a dental caries assessment that documented the presence of decayed, missing, filled, or sealed teeth and tooth surfaces among primary and permanent teeth. Examinations were conducted in mobile trailers by trained and calibrated dentists. As part of the NHANES III dental caries assessment, persons aged 2 years or older received an extensive examination, according to established criteria (19-21). The complete plan and operation of NHANES III has been described elsewhere (6,21-22).

Klein and Palmer used data from a cross-sectional study of public elementary schoolchildren in Hagerstown, Maryland (23). According to the authors, during the time of their study, Hagerstown had a population of approximately 30,000 persons, of whom more than 90 percent were white. The city contained several small manufacturing and industrial units, and included typical retail and wholesale commercial establishments. As part of the cross-sectional study, Klein and colleagues examined 4,416 children aged 6 through 15 years, or approximately 94 percent of the enrolled elementary school population.

Analytical Plan. There were four analytical steps in this investigation. The methods follow, as closely as possible, those described in the original Klein and Palmer work (1), so that results might be compared across investigations. The following paragraphs briefly describe each of the four analytical steps; however, the reader is encouraged to consult the original manuscripts (1,24-26) for additional details.

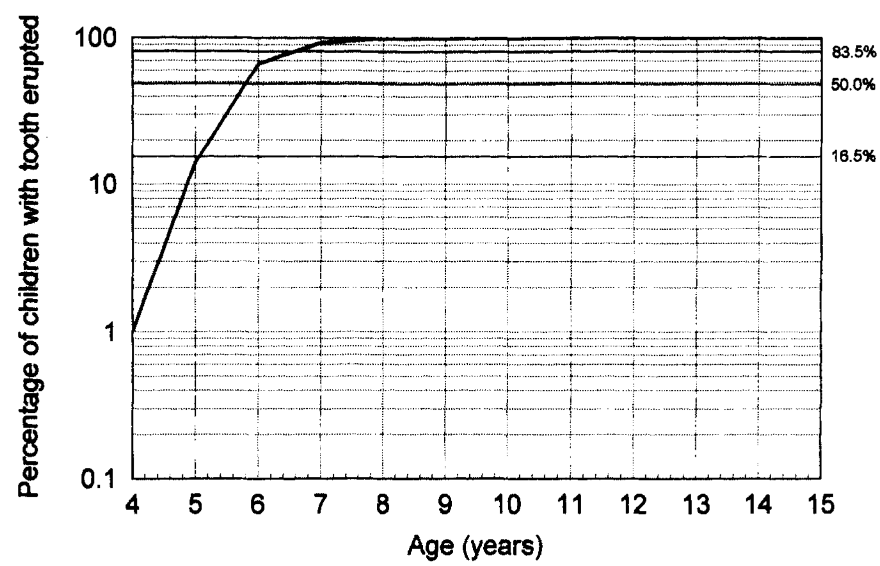
Step One—Derivation of Eruption Schedule. In 1937, Klein and colleagues (24) used a Gaussian normal probability curve to derive an eruption schedule for the permanent teeth. The first step involved calculating the percentage of the population with each tooth type at successive chronological ages. Distributions for the right and left sides were averaged to compensate for any variation from one side of the oral cavity to the other. Once the percentages were compiled for each morphological tooth type, the percentages were transferred to arithmetic probability paper. The x-axis depicted age in years, and the y-axis depicted the percentage of children with each tooth type. The y-axis was represented on a log-scale to compensate for the S-shaped curve that otherwise would result if the y-axis had been represented in base-10. The age (x-axis) at which the Gaussian curve crossed the 50 percent line (y-axis) was an estimate of the mean eruption age for each tooth type (24). The ages (x-axis) during which the Gaussian curve crossed the 16.5 percent and 83.5 percent lines (y-axis) were estimates of the standard deviation about the mean for each tooth type (the 16.5% and 83.5% cut-offs bounded 67 percent of the observations—equal to one standard deviation). In deciding whether use of the normal probability curve was appropriate, Klein and colleagues (24, p 390) concluded:

> There are no inherent reasons for using exclusively the normal probability curve for expressing the eruption of the permanent teeth. However, the considerations which favor the use of the normal curve are that this curve appears to fit the eruption data very satisfactorily, the use of probability paper and of the normal curve is well known, and, finally, a number of advantages may be expected to accrue in connection with the further application of the normal probability theory to data on tooth eruption.

We used the oral examination data from NHANES III for this step and derived an eruption schedule for each morphological tooth type. For illustrative purposes, Figure 1 shows the approximation to the Gaussian curve for the permanent maxillary first molar, with the 16.5 percent, 50 percent (mean), and 83.5 percent intercepts shown. Unlike Klein and colleagues, we were unable to assess whether the eruption data from NHANES IIII fit a Gaussian curve well, because we did not have access to longitudinal eruption data. Although it is possible that eruption times might have changed over time, it is likely that approximation of the Gaussian curve remained valid.

Step Two—Derivation of Posteruptive Tooth Age. Klein and colleagues (25) used a double integral equation to estimate the cumulative number of years each tooth was present in the oral cavity, at any given age. They referred to this time period as the posteruptive tooth age. Klein and colleagues hypothesized that the integral of the Gaussian curve (described in the previous section) could provide the instantaneous rate of eruption of a tooth at any age, or the percentage of children having a tooth erupted at any age. They also reasoned that the percentage of children having a tooth erupted across ages could be derived from the difference in the integral values of the Gaussian curves between two ages. Finally, they hypothesized that, since chronological age was ex-

FIGURE 1
Percentage of Children and Young Adults with Maxillary Permanent First Molar Erupted, by Age: United States, 1988–94



SOURCE: National Center for Health Statistics, Third National Health and Nutrition Examination Survey

pressed in terms of time, the double integral of the Gaussian curve would serve as a mathematical expression for the cumulative posteruptive tooth-years of exposure for any tooth type. According to Klein and Palmer, the general form of the equation was:

$$\int_{-\infty}^{X}\left[\int_{-\infty}^{X}\frac{1}{\sqrt{2\pi}}e^{-(1/2X^2)}dX\right]$$

dX for values of X from –4.0 to +4.0 where

$X=(x - m_x) / \sigma m_x$;

x=age in years;

m_x=mean eruption age; and

σm_x=standard deviation of m_x.

Klein and colleagues noted that the double integral function was an estimate and did not represent an exact value for accumulated years of exposure (24). They also noted, however, that the estimates were sufficiently accurate (27,28) to be used in steps three and four. Again, we used the oral examination data from NHANES III for this step.

Step Three—Derivation of Cumulative Number of Decayed, Missing, and Filled Teeth and Cumulative Posteruptive Tooth Age. We used the NHANES III data set to derive age-specific percentages of children with decayed, missing, and filled permanent teeth, for each morphological tooth type. Values for the right and left sides were averaged to account for any variation from one side of the arch to the other. Afterwards, we converted these percentage values into the number of teeth that were decayed, missing, and filled. The conversion was accomplished by multiplying the percentage values by the mean number of teeth that were present in the oral cavity, at mid-year intervals. To derive the cumulative number of decayed, missing, and filled teeth, we sequentially added the number of decayed, missing, and filled teeth across age groups. We also used the NHANES III data to estimate the cumulative number of years that each morphological tooth type had been exposed in the mouth after eruption.

Step Four—Derivation of Relative Susceptibility Values. In 1941, Klein and colleagues (1) described a technique by which relative susceptibility values for the various morphological tooth types could be represented graphically. To derive the relative susceptibility values, two forms of data were assembled in a single chart. The first form of data (y-axis) consisted of the cumulative number of decayed, missing, and filled teeth, per 100 children of successive chronological age. These data came from Step Three. The second form of data (x-axis) consisted of the cumulative posteruptive tooth age, per 100 children of successive chronological age. These data also came from Step Three. The placement of the resultant curves on the graph showed the relative susceptibility to dental caries of the various morphological tooth types—curves with a flatter slope represented less susceptibility to disease than did those with a steeper slope. Klein and colleagues combined curves with similar slopes into common susceptibility categories. We used the same approach.

Statistical Analysis and Sample Weights. Statistical analysis was conducted using SUDAAN (29), a statistical software program for the personal computer. Full sample weights were used during each of the analytical steps so that estimates would be representative of the US civilian, noninstitutionalized population. We limited all analyses to persons aged 4 through 20 years.

Results

Eruption Schedule. For the maxillary arch, the mean eruption ages

TABLE 1
Function X, Mean Percentage of Children with Permanent Maxillary Teeth Erupted at Mid-year Interval (%I), and Posteruptive Tooth Age (PE), by Tooth Type and Mid-year Age: United States, 1988–94 *[cont. p 177]*

	Central Incisor			Lateral Incisor			Canine			First Premolar		
Age	X	%I	PE	X	%I	PE	X	%I	PE	X	%I	PE
4.5	–2.3	1.7	0.0	–2.8	0.6	0.0	–4.8	0.0	0.0	–4.3	0.0	0.0
5.5	–1.3	9.5	0.0	–1.9	3.5	0.0	–4.0	0.0	0.0	–3.5	0.0	0.0
6.5	–0.1	40.0	0.3	–1.0	15.0	0.1	–3.2	0.0	0.0	–2.7	0.0	0.0
7.5	1.0	85.0	1.1	–0.1	44.0	0.4	–2.4	1.2	0.0	–1.9	3.2	0.0
8.5	2.1	98.8	2.1	0.8	79.8	0.9	–1.6	4.4	0.0	–1.1	11.5	0.1
9.5	3.3	100	3.3	1.7	94.9	1.8	–0.9	17.5	0.1	–0.3	36.0	0.3
10.5	4.4	100	4.3	2.7	98.6	2.7	–0.1	47.0	0.4	0.5	66.0	0.7
11.5	5.5	100	5.3	3.6	99.4	3.6	0.7	70.5	0.8	1.3	88.5	1.3
12.5	6.7	100	6.3	4.5	100	4.6	1.5	88.0	1.5	2.1	98.7	2.1
13.5	7.8	100	7.3	5.4	100	5.6	2.3	96.9	2.3	2.8	100	2.8
14.5	8.9	100	8.3	6.3	100	6.6	3.0	100	3.0	3.6	100	3.6
15.5	10.1	100	9.3	7.3	100	7.6	3.8	100	3.8	4.4	100	4.6
16.5	11.2	100	10.3	8.2	100	8.6	4.6	100	4.8	5.2	100	5.6
17.5	12.3	100	11.3	9.1	100	9.6	5.4	100	5.8	6.0	100	6.6
18.5	13.5	100	12.3	10.0	100	10.6	6.2	100	6.8	6.8	100	7.6
19.5	14.6	100	13.3	10.9	100	11.6	6.9	100	7.8	7.6	100	8.6

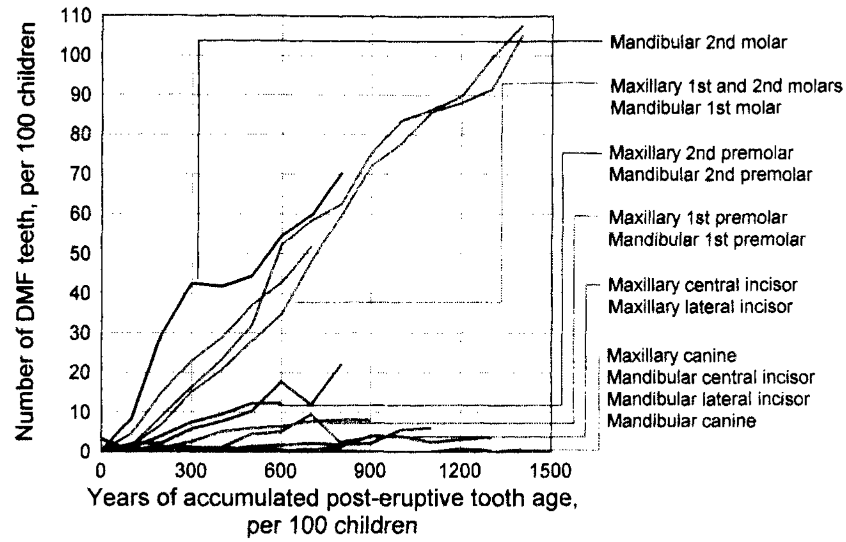
Source: National Center for Health Statistics, Third National Health and Nutrition Examination Survey

were: central incisor=6.6 years (one standard deviation [SD] range=5.7–7.5 years), lateral incisor=7.6 years (one SD range=6.6–8.6 years), canine=10.6 years (one SD range=9.3–11.9 years), first premolar=9.9 years (one SD range=8.7–11.1 years), second premolar=10.7 years (one SD range=9.3–12.1 years), first molar=5.8 years (one SD range=5.1–6.5 years), and second molar=11.5 years (one SD range=10.2–12.8 years). For the mandibular arch, the mean eruption ages were: central incisor=5.7 years (one SD range=4.8–6.6 years), lateral incisor=6.8 years (one SD range=5.8–7.8 years), canine=9.8 years (one SD range=8.6–11.0 years), first premolar=9.9 years (one SD range=8.7–11.1 years), second premolar=10.7 years (one SD range=9.4–12.0 years), first molar=5.7 years (one SD range=4.8–6.6 years), and second molar=10.9 years (one SD range=9.8–12.0 years).

Posteruptive Tooth Age. Table 1 contains posteruptive tooth age (PE) data for the maxillary arch. In general, the permanent maxillary first molars were the first to erupt into the maxillary arch and had the highest posteruptive tooth age among those aged 19.5 years. The permanent maxillary central and lateral incisors followed closely behind. The permanent maxillary canine, first premolar, second premolar, and second molar were among the last tooth types to erupt into the maxillary arch.

Table 2 contains PE values for the mandibular arch. In general, the pattern of eruption and posteruptive tooth age was the same in the mandibular arch as it was in the maxillary arch. The first molars, central incisors,and lateral incisors were generally the first to erupt, whereas the canines, premolars, and second molars erupted several years afterwards. Among those aged 19.5 years, the cu-

FIGURE 2
Number of Decayed, Missing,and Filled Teeth vs Years of Accumulated Posteruptive Tooth Age: United States, 1988–94



SOURCE: National Center for Health Statistics, Third National Health and Nutrition Examination Survey

TABLE 1
Function X, Mean Percentage of Children with Permanent Maxillary Teeth Erupted at Mid-year Interval (%I), and Posteruptive Tooth Age (PE), by Tooth Type and Mid-year Age: United States, 1988–94 *[cont. from p 176]*

	Second Premolar			First Molar			Second Molar		
Age	X	%I	PE	X	%I	PE	X	%I	PE
4.5	–4.4	0.0	0.0	–1.8	3.9	0.0	–5.7	0.0	0.0
5.5	–3.7	0.0	0.0	–0.4	29.0	0.2	–4.9	0.0	0.0
6.5	–3.0	0.0	0.0	0.9	79.0	1.0	–4.1	0.0	0.0
7.5	–2.3	1.2	0.0	2.3	88.6	2.3	–3.3	0.0	0.0
8.5	–1.6	4.8	0.0	3.7	100	3.7	–2.4	0.0	0.0
9.5	–0.9	17.6	0.1	5.0	100	4.7	–1.6	3.0	0.0
10.5	–0.1	40.1	0.3	6.4	100	5.7	–0.8	20.0	0.1
11.5	0.5	69.0	0.7	7.8	100	6.7	0.0	50.0	0.4
12.5	1.2	89.8	1.3	9.2	100	7.7	0.9	74.1	1.0
13.5	2.0	93.6	2.0	10.5	100	8.7	1.7	91.6	1.7
14.5	2.7	100	2.7	11.9	100	9.7	2.5	100	2.5
15.5	3.4	100	3.4	13.3	100	10.7	3.3	100	3.5
16.5	4.1	100	4.4	14.6	100	11.7	4.2	100	4.5
17.5	4.8	100	5.4	16.0	100	12.7	5.0	100	5.5
18.5	5.5	100	6.4	17.4	100	13.7	5.8	100	6.5
19.5	6.2	100	7.4	18.7	100	14.7	6.6	100	7.5

Source: National Center for Health Statistics, Third National Health and Nutrition Examination Survey

TABLE 2

Function X, Mean Percentage of Children with Permanent Mandibular Teeth Erupted at Mid-year Interval (%I), and Posteruptive Tooth Age (PE), by Tooth Type and Mid-year Age: United States, 1988–94 ***[cont. p 179]***

	Central Incisor			Lateral Incisor			Canine			First Premolar		
Age	X	%I	PE	X	%I	PE	X	%I	PE	X	%I	PE
4.5	–1.5	3.9	0.0	–2.4	0.0	0.0	–4.3	0.0	0.0	–4.7	0.0	0.0
5.5	–0.2	23.9	0.3	–1.4	2.0	0.0	–3.5	0.0	0.0	–3.8	0.0	0.0
6.5	0.9	74.1	1.0	–0.3	17.2	0.3	–2.6	0.0	0.0	–2.9	0.0	0.0
7.5	2.2	88.7	2.2	0.7	52.0	0.9	–1.8	0.4	0.0	–2.1	0.0	0.0
8.5	3.4	100	3.4	1.8	85.5	1.8	–1.0	2.8	0.1	–1.2	0.4	0.0
9.5	4.6	100	4.4	2.8	100	2.8	–0.2	31.8	0.3	–0.3	55.7	0.2
10.5	5.8	100	5.4	3.9	100	3.9	0.6	46.1	0.7	0.5	38.1	0.7
11.5	7.0	100	6.4	5.0	100	43.9	1.4	93.4	1.4	1.4	76.0	1.4
12.5	8.2	100	7.4	6.0	100	5.9	2.2	100	2.2	2.2	100	2.2
13.5	9.4	100	8.4	7.1	100	6.9	3.0	100	3.0	3.1	100	3.1
14.5	10.6	100	9.4	8.1	100	7.9	3.8	100	3.8	4.0	100	4.0
15.5	11.8	100	10.4	9.2	100	8.9	4.6	100	4.8	4.8	100	5.0
16.5	13.0	100	11.4	10.2	100	9.9	5.4	100	5.8	5.7	100	6.0
17.5	14.2	100	12.4	11.3	100	10.9	6.2	100	6.8	6.5	100	7.0
18.5	15.4	100	13.4	12.3	100	11.9	7.0	100	7.8	7.4	100	8.0
19.5	16.6	100	14.4	13.4	100	12.9	7.8	100	8.8	8.2	100	9.0

Source: National Center for Health Statistics, Third National Health and Nutrition Examination Survey.

mulative posteruptive tooth age for the mandibular arch was slightly higher than was that for the maxillary arch (Table 3).

Relative Susceptibility to Dental Caries. The relative susceptibility to dental caries of the different morphological permanent tooth types is shown in Figure 2. Six categories of susceptibility were apparent: Category 1: mandibular second molar (representing the most susceptible tooth type); Category 2: maxillary first and second molars and mandibular first molar; Category 3: maxillary and mandibular second premolars; Category 4: maxillary and mandibular first premolars; Category 5: maxillary central and lateral incisors; and Category 6: maxillary and mandibular canines and mandibular central and lateral incisors (representing the least susceptible tooth types). In general, the pattern of eruption and posteruptive tooth age was the same in the mandibular arch as it was in the maxillary arch. The first molars, central incisors, and lateral incisors were generally the first to erupt, whereas the canines, premolars, and second molars erupted several years afterwards. Among those aged 19.5 years, the accumulated posteruptive tooth age for the mandibular arch was slightly higher than that for the maxillary arch (Table 3). This difference was due to the fact that the permanent mandibular teeth generally erupted into the oral cavity before the maxillary teeth erupted.

Discussion

In general, both this investigation and the original Klein and Palmer study found the molar teeth to be much more susceptible than the incisor or canine teeth; however, a number of differences between this investigation and the original study were worth noting. For example, this investigation found six categories of susceptibility, whereas Klein and Palmer identified five categories. One possible explanation for this difference is that the sample size used in this investigation

FIGURE 3

Comparison of First Molar Curves by Source of Data

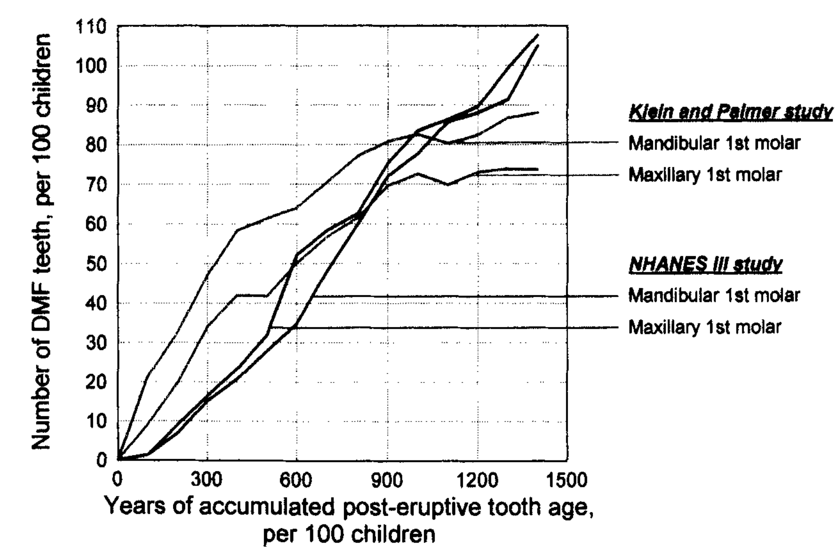


TABLE 2
Function X, Mean Percentage of Children with Permanent Mandibular Teeth Erupted at Mid-year Interval (%I), and Posteruptive Tooth Age (PE), by Tooth Type and Mid-year Age: United States, 1988–94 *[cont. from p 178]*

	Second Premolar			First Molar			Second Molar		
Age	X	%I	PE	X	%I	PE	X	%I	PE
4.5	–4.9	0.0	0.0	–1.6	0.2	0.0	–6.0	0.0	0.0
5.5	–4.1	0.0	0.0	–0.3	28.5	0.3	–5.1	0.0	0.0
6.5	–3.3	0.0	0.0	0.9	71.8	1.0	–4.1	0.0	0.0
7.5	–2.5	0.0	0.0	2.2	88.9	2.2	–3.2	0.0	0.0
8.5	–1.7	0.0	0.0	3.5	100	3.5	–2.3	0.0	0.0
9.5	–0.9	11.9	0.1	4.7	100	4.5	–1.3	1.3	0.0
10.5	–0.1	24.1	0.3	6.0	100	5.5	–0.4	7.0	0.2
11.5	0.6	59.2	0.8	7.3	100	6.5	0.5	56.4	0.7
12.5	1.4	93.2	1.5	8.5	100	7.5	1.5	91.1	1.5
13.5	2.2	93.2	2.2	9.8	100	8.5	2.4	95.0	2.4
14.5	3.0	100	3.0	11.1	100	9.5	3.3	100	3.3
15.5	3.8	100	3.8	12.3	100	10.5	4.3	100	4.3
16.5	4.6	100	4.8	13.6	100	11.5	5.2	100	5.3
17.5	5.4	100	5.8	14.9	100	12.5	6.1	100	6.3
18.5	6.2	100	6.8	16.1	100	13.5	7.1	100	7.3
19.5	7.0	100	7.8	17.4	100	14.5	8.0	100	8.3

Source: National Center for Health Statistics, Third National Health and Nutrition Examination Survey.

TABLE 3
Cumulative Posteruptive Tooth Age for One Side of Oral Cavity and Both Sides of Oral Cavity, per 100 Children, by Arch and Mid-year Age: United States, 1988–94

	Accumulated Posteruptive Tooth Age per 100 Children			
	Maxillary Arch		Mandibular Arch	
Age	1 Side	Both Sides	1 Side	Both Sides
4.5	0.0	0.0	0.0	0.1
5.5	0.3	0.6	0.6	1.2
6.5	1.5	2.9	2.3	4.7
7.5	3.8	7.5	5.3	10.6
8.5	6.9	13.8	8.8	17.6
9.5	10.2	20.4	12.4	24.7
10.5	14.1	28.2	16.8	33.5
11.5	18.8	37.6	22.1	44.2
12.5	24.4	48.8	28.1	56.3
13.5	30.3	60.6	34.4	68.9
14.5	36.4	72.8	40.9	81.7
15.5	42.9	85.7	47.7	95.3
16.5	49.9	99.7	54.7	109.3
17.5	56.9	113.7	61.7	123.3
18.5	63.9	127.7	68.7	137.3
19.5	70.9	141.7	75.7	151.3

Source: National Center for Health Statistics, Third National Health and Nutrition Examination Survey.

(~10,500 children) was larger than the sample size used by Klein and Palmer (~6,300 children). The larger sample size might have provided a greater ability to differentiate variation among the various morphological tooth types.

A second difference between the two studies was a change in relative susceptibility values. In the Klein and Palmer study, for example, the mandibular first premolar was less susceptible than the maxillary central and lateral incisors, whereas in this investigation, the mandibular first premolar was more susceptible than either of the other tooth types. One explanation is that while reductions in dental caries prevalence have occurred for all tooth surfaces, percent reductions have been greatest among smooth surfaces (30). Given that mandibular first premolars have a greater number of pit-and-fissure surfaces than do the maxillary central or lateral incisors, the relative percent reduction in dental caries prevalence expected for the premolars could explain the change in relative susceptibility across the two studies.

A third difference was that the gap

FIGURE 4
Comparison of Second Molar Curves by Source of Data

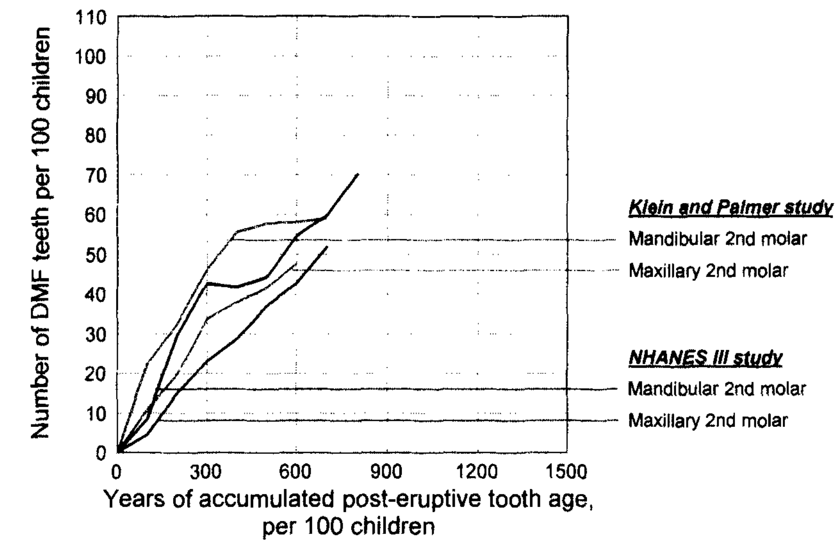
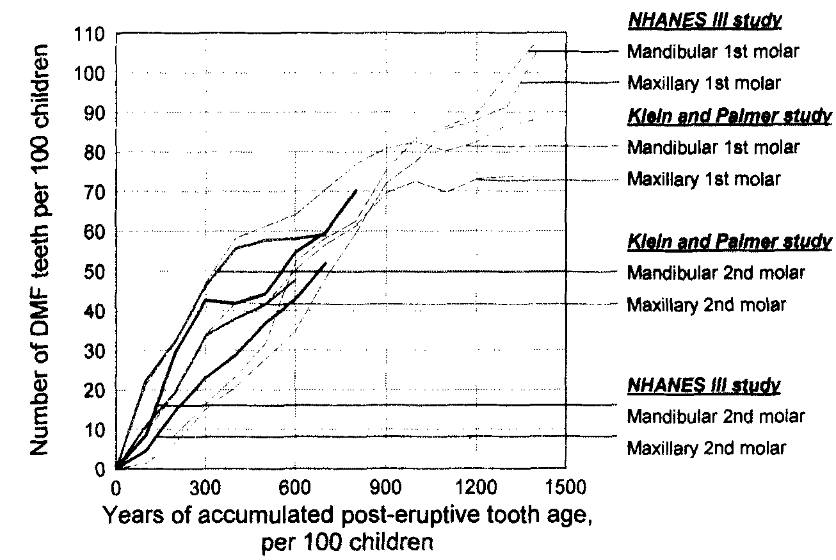


FIGURE 5
Comparison of First and Second Molar Curves by Source of Data



in relative susceptibility values between first and second molars in the Klein and Palmer study was minimal, whereas the gap in relative susceptibility values between first and second molars was substantial in this investigation, particularly among mandibular molars (Figure 3). It is possible that the advent of dental sealants as a preventive measure has resulted in this shift in susceptibility over time. Recent national data (31) have shown that mandibular first molars are more likely to receive a sealant than are mandibular second molars. Dental sealants provide nearly complete protection from dental caries when they are placed over the pits and fissures of susceptible teeth (32,33). It is possible that the selective use of dental sealants on mandibular first molars reduced the relative susceptibility of these teeth to a point equal to the relative susceptibility of mandibular second molars found during the Klein and Palmer study. If dental practitioners had been equally likely to place dental sealants on mandibular second molars, perhaps the relative susceptibility of these teeth might have been reduced, as well.

A final difference between the two studies was that the slopes for most of the susceptibility curves were less steep in this investigation than they were in the Klein and Palmer study. Specifically, the slopes for the curves of the maxillary and mandibular premolar, canine, and incisor from this investigation were consistently flatter than were the slopes for similar tooth types from the Klein and Palmer study, regardless of posteruptive tooth age (data not shown). This finding provided additional evidence of a decline in dental caries experience among children and young adults in the United States over the last several decades.

For some morphological tooth types, however, the slopes of the curves from this investigation were more steep than were those from the study. Figure 4 shows the side-by-side comparison of maxillary and mandibular first molar data from each investigation. The slopes for the Klein and Palmer curves were more steep than the NHANES III curves from 0 years of cumulative posteruptive tooth age through approximately 800 to 1,000 years of cumulative posteruptive tooth age, a difference that supported a decline in dental caries prevalence over time. The curves, however, overlapped at the 800 to 1,000 posteruptive tooth age mark, and as years of accumulative posteruptive tooth age increased, the NHANES III curves assumed a higher relative susceptibility position than did the Klein and Palmer curves. The intersection of the curves suggested that factors explaining a decline in dental caries prevalence might have had a greater effect during the first five to 10 years posteruption than they might have had later in the tooth's posteruptive life.

The intersection also might have been explained by a cohort effect. For example, shorter periods of posteruptive tooth age (x-axis) also reflected children who were born more recently, during a time when preventive services such as dental sealants were more prevalent than they were five to 10 years earlier (30). The fact that the relative susceptibility curves from this investigation appear to have a constant slope beyond 1,000 years of cumulative posteruptive tooth age may be less a reflection of constant susceptibility, and more a reflection of relatively dramatic reductions in susceptibility among children born more recently. Perhaps contemporary susceptibility curves illustrate an evolving process, one in which reductions in relative susceptibility found during shorter periods of posteruptive tooth age will eventually occur during longer periods of posteruptive tooth age into the future. It will be interesting to test whether the observed leveling of the susceptibility curves in the Klein and Palmer study will occur in the United States over time.

Figure 5 shows a comparison of maxillary and mandibular second molar data from each study. Here again, for higher values of cumulative posteruptive tooth age, the slopes for the NHANES III curves were more steep than were those for the Klein and Palmer curves. It is likely that the intersection of curves might be explained by the same factors described in the preceding paragraph.

This investigation had a number of limitations. The first was that this investigation did not provide explanations for changes in relative susceptibility. We have already mentioned a few likely explanations, such as fluoride and dental sealants, but changes could have been explained equally well by diet, treatment philosophies, access to dental care, dental insurance, and other factors.

The second limitation was that since children were not followed over time, the cross-sectional NHANES III data provided only an estimate of susceptibility. Although the use of cross-sectional data was a limitation, it represented a more economical approach to the research problem, given the costs that would have been incurred by a longitudinal study.

The third limitation was that NHANES III did not match its dental caries scoring criteria with that of the original Klein and Palmer investigation. Although the scoring criteria were not identical, both the Klein and Palmer (26) and NHANES III dental caries assessments (6) were based on lesions into the dentin. Thus, it would be unlikely that scoring differences would have affected the relative placement of curves across studies.

The fourth limitation was that the sampling methods for this investigation did not match those of the Klein and Palmer study. We used children aged 4 through 20 years, whereas Klein and Palmer used children aged 6 through 15 years. In addition, we used a sample that was representative of all civilian, noninstitutionalized persons in the United States, whereas Klein and colleagues used a study population that was primarily white and represented a middle-income population in a relatively small Maryland town. It is possible that gaps in relative susceptibility could have been explained by differences in sample composition between the two study populations. If study methods were the primary explanation of differences across investigations, then less credence would be given to the potential impact of fluoride, dental sealants, and other oral health-related factors on the difference. At this point, it is impossible to know how much of an influence differences in study methods had on the results of this investigation. We believe that the findings from this investigation are still useful, however, as they are more representative of the United States than are the findings from the Klein and Palmer study and, as such, are more valid.

This investigation also has a number of strengths. The NHANES III data used in this investigation were representative of the US civilian, noninstitutionalized population, and thus were able to compensate for variations in race, ethnicity, and sociodemographics. In addition, the reliability scores for the oral examination component of NHANES III were generally very high (6), an indication that the permanent teeth were scored consistently. Finally, because our investigation used the same methods and analytical techniques employed in the Klein and Palmer study, comparisons across studies were appropriate.

In summary, this investigation derived dental caries susceptibility values for the various morphological tooth types from a current and nationally representative dataset. The study revealed six categories of susceptibility, with molars being more susceptible to dental caries than incisors, canines, or premolars. The study also showed that the decline in dental caries prevalence has been accompanied by changes in the relative susceptibilities of the various morphological tooth types over time. Preventive measures, such as dental sealants and fluorides, were likely explanations for the changes in overall susceptibility and relative susceptibility (34). As molars remain the most susceptible morphological tooth types to dental caries in the oral cavity, future research should explore the specific factors that are responsible for this finding. In addition, designers of future longitudinal studies should consider using their investigations to assess susceptibility, if the opportunity arises.

Acknowledgments

This investigation was supported by the Centers for Disease Control and Prevention, via an Intergovernmental Personnel Act agreement (CDC 99IPA06631). The authors would like to acknowledge the National Center for Health Statistics as the original source of public-use data. The analysis, interpretations, and conclusions derived from this manuscript should be credited solely to the authors.

References

1. Klein H, Palmer CE. Studies on dental caries. XII. Comparison of the caries susceptibility of the various morphological types of permanent teeth. J Dent Res 1941;20:203-16.
2. Burt BA. Influences for change in the dental health status of populations: an historical perspective. J Public Health Dent 1978;38:272-88.
3. US Department of Health and Human Services, National Center for Health Statistics. Decayed, missing, and filled teeth among persons 1-74 years, United States, 1971-1974. Washington, DC: Government Printing Office, 1981; DHHS pub no (PHS) 81-1678.
4. US Department of Health and Human Services, National Institutes of Health, National Institute of Dental Research. The prevalence of dental caries in United States children, 1979-1980. Washington, DC: Government Printing Office, 1982; NIH pub no (NIH) 82-2245.
5. US Department of Health and Human Services, National Institutes of Health, National Institute of Dental Research. Oral health of United States children. Washington, DC: Government Printing Office, 1989; NIH pub no (NIH) 89-2247.
6. Kaste LM, Selwitz RH, Oldakowski RJ, Brunelle JA, Winn DM, Brown LJ. Coronal caries in the primary and permanent dentition of children and adolescents 1-17 years of age: United States, 1988-1991. J Dent Res 1996;75(Spec Iss):631-41.
7. Burt BA. Prevention policies in the light of the changed distribution of dental caries. Acta Odontol Scand 1998;56:179-86.
8. Vargas CM, Crall JJ, Schneider DA. Sociodemographic distribution of pediatric dental caries: NHANES III, 19881994 [see comments]. J Am Dent Assoc 1998;129: 1229-38. Comment in: J Am Dent Assoc 1998;129:1526.
9. Graves RC, Bohannan HM, Disney JA, Stamm JW, Bader JD, Abernathy JR. Recent dental caries and treatment patterns in US children. J Public Health Dent 1986; 46:23-9.
10. Berman DS, Slack GL. Susceptibility of tooth surfaces to carious attack. A longitudinal study. Br Dent J 1973;134:135-9.
11. Chestnutt IG, Schafer F, Jacobson AP, Stephen KW. Incremental susceptibility

of individual tooth surfaces to dental caries in Scottish adolescents. Community Dent Oral Epidemiol 1996;24:11-16.
12. Cleaton-Jones P, Walker AR. Patterns of tooth vulnerability to caries in South African high school pupils. Community Dent Oral Epidemiol 1980;8:203-7.
13. Dummer PM, Oliver SJ, Hicks R, Kindon A, Addy M, Shaw WC. Factors influencing the initiation of carious lesions in specific tooth surfaces over a 4-year period in children between the ages of 11-12 years and 15-16 years. J Dent 1990;18:190-7.
14. Edward S. Dental caries on adjacent approximal tooth surfaces in relation to order of eruption. Acta Odontol Scand 1997;55:2730.
15. Hujoel PP, Isokangas PJ, Tiekso J, Davis S, Lamont RJ, DeRouen TA, et al. A reanalysis of caries rates in a preventive trial using Poisson regression models. J Dent Res 1994;73:573-9.
16. King NM, Shaw L, Murray JJ. Caries susceptibility of permanent first and second molars in children aged 5-15 years. Community Dent Oral Epidemiol 1980;8:151-8.
17. Richardson PS, McIntyre IG. Susceptibility of tooth surfaces to carious attack in young adults. Community Dent Health 1996;13:163-8.
18. Virtanen JI, Bloigu RS, Larmas MA. Effect of early or late eruption of permanent teeth on caries susceptibility. J Dent 1996;24:245-50.
19. Radike AW. Criteria for diagnosis of dental caries. In: Proceedings of the conference on the clinical testing of cariostatic agents. Chicago, IL: American Dental Association, 1972:87-8.
20. US Department of Health and Human Services. National Institutes of Health. National Institute of Dental Research. Oral health surveys of the National Institute of Dental Research. Diagnostic criteria and procedures. Washington, DC: Government Printing Office, 1991; NIH pub no (NIH) 91-2870.
21. US Department of Health and Human Services, Centers for Disease Control and Prevention, National Center for Health Statistics (1994). Plan and operation of the third national health and nutrition examination survey, 1988-94. Hyattsville, MD: National Center for Health Statistics, 1994; DHHS pub no (PHS) 94-1308.
22. Drury TF, Winn DM, Snowden CB, Kingman A, Kleinman DV, Lewis B. An overview of the oral health component of the 1988-1991 National Health and Nutrition Examination Survey (NHANES III—Phase 1). J Dent Res 1996;75(Spec Iss):620-30.
23. Klein H, Palmer CE, Knutson JW. Studies on dental caries. I. Dental status and dental needs of elementary schoolchildren. Public Health Rep 1938;53:751-65.
24. Klein H, Palmer CE, Kramer M. Studies on dental caries. II. The use of the normal probability curve for expressing the age distribution of eruption of the permanent teeth. Growth 1937;1:385-94.
25. Klein H. Palmer CE, Kramer M. Studies on dental caries. III. A method of determining posteruptive tooth age. Growth 1938;2:149-58.
26. Klein H, Palmer CE. Studies on dental caries. X. A procedure for the recording and statistical processing of dental examination findings. J Dent Res 1940;19:243-56.
27. Cattell P. Dentition as a measure of maturity. Harvard mongraphs in education. No 9. Cambridge, MA: Harvard University Press, 1928.
28. Cohen JT. The dates of eruption of the permanent teeth in a group of Minneapolis children. J Am Dent Assoc 1928;15:2337-43.
29. Research Triangle Institute. SAS-callable SUDAAN for Windows 95/NT. Release 7.5.2. Research Triangle Park, NC: Research Triangle Institute, 1998.
30. McDonald SP, Sheiham A. The distribution of caries on different tooth surfaces at varying levels of caries—a comparison of data from 18 previous studies. Community Dent Health 1992;9:39-48.
31. Selwitz RH, Winn DM, Kingman A, Zion GR. The prevalence of dental sealants in the US population: findings from NHANES III, 1988-1991. J Dent Res 1996;75 (Spec Iss):652-60.
32. Ripa LW. Occlusal sealants: rationale and review of clinical trials. Int Dent J 1980;30:127-39.
33. Ripa LW. Sealants revisited: an update of the effectiveness of pit and fissure sealants. Caries Res 1993;27(Suppl 1):77-82.
34. Bratthall D, Hansel Petersson G, Sundberg H. Reasons for the caries decline: what do the experts believe? Euro J Oral Sci 1996;104:416-22.