E. Steven Duke
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The Need for Restorative Dentistry and Caries Prevention in the U.S. Population

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Abstract

The National Health and Nutrition Examination Survey III (NHANES III) and other representative studies of the U.S. population have provided current estimates of dental caries and related tooth conditions, as well as related demographic and health behavioral factors. Through Healthy People 2010 goals, a national initiative is under way to understand and address long-standing disparities in oral health. Also, disparities in oral health were a major focus of the recently released Surgeon General's Report on Oral Health [U.S. Department of Health and Human Services, 2000a].

For age groups across the life span this paper will summarize the need for restorative dentistry and its disparity between various subpopulations. Of course disparity of need for primary caries prevention, both at the community and individual levels, is an even more pressing challenge, because oral health of the population will not be attained by secondary restoration or tertiary replacement of tooth structure and function alone.

Dental caries is an age-dependent disease. Its prevalence, and the prevalence of health behaviors associated with caries, are significantly related to socioeconomic status (SES, family income), level of education of the head of household, ethnicity and race.

Caries is now experienced across the life span and somewhat less dominant in childhood and adolescence, but this consequence of the caries decline may hide important features of the disease distribution by age:

(a) There is an epidemic of early childhood caries in lower SES and some racial/ethnic groups, which has not been adequately addressed. A heavy restorative emphasis alone has not and will not adequately deal with this preventable disease of early childhood.

(b) Considering all age groups, the greatest burden of untreated caries still occurs in the early years of elementary school. This is so for Whites, African Americans and Hispanic Mexican Americans. All three groups differ from one another in caries prevalence (% affected), and in the proportion of caries which remains untreated (DS+ds/DFS+dfs). White adults, with greater access to dental care have higher prevalence of defective restorations, defective crowns and bridges, and tooth fractures associated with restoration (iatrogenesis). Blacks and Mexican Americans who have less access to care, have higher prevalence of pulpal pathology and retained roots (consequences of untreated disease). Yet the latter groups are no more likely to become edentulous, and this is an indication of present limits of restorative technology, preventive behavior by the public and of dental practitioners, and professional technology transfer.

Access to individual preventive and restorative dental care varies significantly with age, family income, level of education, race/ethnicity, and, if applicable, institutionalization.

The end point of failure to prevent caries and restore teeth, edentulousness in later life, is associated with lower educational attainment and also, thereafter, with very low dental attendance, making oral cancer prevention and early detection problematic.

By simultaneously controlling for a number of variables affecting oral health of adults, regression analysis of NHANES III has shown that:

1. African Americans have more restorative tooth conditions (RTCs) involving pulp pathology or retained roots than Whites (OR 2.2, $p<0.001$)

2. Whites are more likely to have had a dental visit in the past year than Mexican Americans (OR 1.5, $p<0.001$)

3. Adults of lower socioeconomic status (SES) are:

a) more likely to have untreated coronal caries (OR 4.9, $p<0.001$),

b) more likely to have untreated root caries (OR 5.8, $p<0.001$),

c) more likely to have RTCs involving pulp pathology or retained roots (OR 5.8, $p<0.001$), and

d) less likely to have visited a dental professional in the past year (OR 3.8, $p<0.001$), than are U.S. adults of higher SES.

The attainment of Goals for Healthy People 2010, to reduce these caries related disparities in oral health through both community and individual prevention and dental restoration, is our challenge and responsibility.

In considering the "population in need of restorative dentistry" one might include conditions such as erosion, abrasion and less obvious tooth fractures, as well as caries. The epidemiology of these other conditions is not described for the U.S. population. It is nevertheless clear that dental caries, crown and root caries, and its retreatment due to failed restoration and recurrence of caries, is far and away the major cause for tooth restoration.

In attempting to summarize the need for restorative dentistry in the U.S. population it is also very apparent that the discussion cannot proceed without simultaneously considering the need for caries prevention—both at the individual and community level. Fluorides, particularly community water fluoridation and fluoride toothpastes, have caused the greatest reduction in the population of need. Counter effects to prevention are increased longevity, which increases the time teeth are at risk of caries, and slowly increasing access to dental care including tooth restoration. Therefore, it is not possible to address the need by considering tooth restoration and replacement alone, and we have known this far longer than we have known the full extent of the benefits of fluorides.

Access to restorative dental care implies access to a measure of individual caries prevention and health education. In addition over 50% of the U.S. population and over 60% of the population using a public water supply use fluoridated water. The market penetration of fluoride toothpaste is very high, though we lack information as to whether some sectors of the population without water fluoridation may not use fluoride toothpastes regularly, and so be considered fluoride deficient.

Professional fluoride and sealant applications and school-based fluoride and sealant programs are today recommended for individuals and groups at risk of caries.

The dietary factors in caries risk are not clearly defined today on a population basis. To conclude that diet plays little role in caries today is not only bad logic, but also ignores what we know about the necessity for suitable substrates in those individuals who are caries active.

Studies are in conflict as to the contribution of form and frequency of sugar and cooked starch foods to caries. We are ignorant about the contri-

bution of sugar drinks to caries in the p
this major etiologic factor for many of
was shed on this matter recently by th
who described the relationship betwee
quency of sugar exposure using the "in
demineralization is assessed in plaque-c
oral conditions in humans. In the absen
old frequency of sugar exposures nece
ineralization was three per day, and th
with frequency of sugar exposure. In th
frequency could be tolerated without de

With this evidence, what can or
but widely disseminated information that
3 should not use fluoride toothpaste, all
pervision? A third of U.S. preschool chil
early or late evidence of caries. There is
understand that the benefits of fluorid
increased risk of whitening fluorosis. M
sis is a useful way to conduct surveil
appropriate recommendations for fluori
be to reduce very mild and mild fluoro
the caries preventive benefit. Topical use
at the site of acid challenge comes with
of topical versus systemic action of fl
fluoridation provides the most available,
centration of fluoride at potential sites o
sium will deal more specifically with di
factors, but clearly there are poorly und
in the population.

Univariate Relationships of Ne
Preventive Care

This paper will broadly attempt
storative dentistry in the U.S. populatio
the prevalence of caries across the life s

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lividual patients. Some light
at the University of Leeds,
, fluoride exposure and fre-
ı vivo" oral device, in which
namel slabs under controlled
uoride toothpaste, the thresh-
) consistently produce dem-
ee of demineralization rose
ce of fluoride a higher sugar
ization [Duggal et al., 2000].
bout current unsubstantiated
hildren under the age of 2 or
mall amount under adult su-
m low income families show
spread professional failure to
ot to be had without some
ng the prevalence of fluoro-
n fluoride intake and make
ucts, but the aim should not
ero, thereby also discarding
rides for their bioavailability
luorosis risk. The discussion
has also ignored that water
ian and lowest effective con-
Other papers in this sympo-
alivary and fluoride etiologic
issues with regard to caries

Restorative and

trate the unmet need for re-
requires some discussion of
d definition of those groups

who have the greater burden of the disease and its consequence—tooth loss. This in turn necessitates an account of the relative access of subpopulations to dental services, including prevention and tooth restoration.

We have known for many decades that caries varies with age, gender, family income, level of education, race/ethnicity and, if applicable, institutionalization. These contemporary univariate relationships will be reviewed. The more complex question is whether certain racial/ethnic, socioeconomic or other groups who have more caries or less treatment and prevention do so inherently, or merely as a consequence of other explanatory variables of known significance. When we understand this we are better placed to propose explanatory hypotheses for disparities in caries and in access to its treatment and prevention in those subpopulations. These in turn can be tested prospectively for interventions to prevent the disease and treat its consequences by restoration. A blanket, whole population, uniform approach is clearly no longer efficient, due to the skewed caries distribution.

Two sources of data and analysis from the Third National Health and Nutrition Examination Survey (NHANES III) are used in this review [Kleinman and Drury, 1996; National Institute of Dental & Craniofacial Research, 2000]. Other sources for this discussion are the Oral Health Progress Reviews for Healthy People 2000 [Wagener and Sondik, 1999], which drew on NHANES III, two periodic surveys by the National Center for Health Statistics (NCHS)—the Medical Expenditure Panel Survey 1996 (MEPS) and the Behavioral Risk Factor Surveillance Survey 1995-98 (BRFSS)—and Vital Statistics of the U.S. Census Bureau for 1997. Results are also published from the San Antonio site for the Second International Collaborative Study of Oral Health Outcomes (ICS II) [Chen et al., 1997]. A study of early childhood caries in South Texas sponsored by the National Center for Health Statistics (NCHS) is also utilized [Garcia-Godoy et al., 1995] in this paper.

There is a long-standing epidemic of early childhood caries in certain groups of children. One third of lower income children attending Women, Infants and Children (WIC) Nutrition Centers have caries and over half of some Native American groups of preschoolers are affected [Proceedings of the Conference on Early Childhood Caries, 1998]. A restorative approach has proven very costly [Griffin et al., 2000; Kanellis et al., 2000] and is often ineffective as measured by need for retreatment [Carr, 2000]. Innovative family and group preventive approaches are being explored slowly,

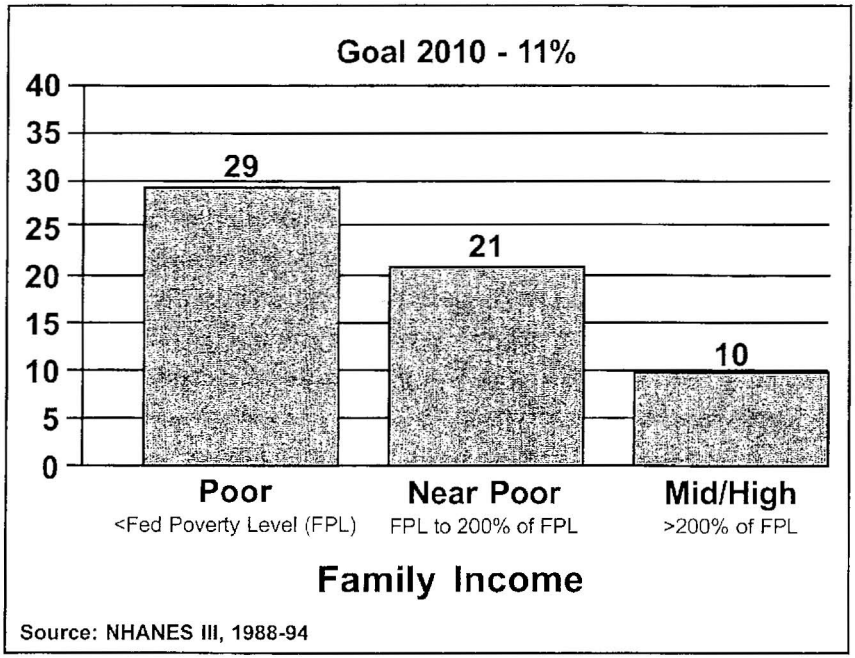


FIG. 1. Percentage of children ages 2-4 years who have ever had tooth decay.

which utilize effective health and dietary behavior change methods, remineralization of caries as well as less invasive restoration where possible.

Figure 1 shows the percentage of children aged 2-4 who have ever had tooth decay, stratified by family income. Children from families with income below the Federal Poverty Level (< $16,000 for a family of 4) have a higher prevalence than those from families of income $16-32,000, who in turn have greater caries than children from families of mid- to higher income. The goal we have set ourselves for 2010 is that only 11% of 2-4 year old children overall would have experienced caries [U.S. Department of Health and Human Services 2000b].

Figure 2 illustrates a similar relationship for children aged 15 who have untreated tooth decay (DT), stratified by level of educational attainment of the head of household. Income and educational attainment are commonly covariates. The Goal for 2010 is set at 15% of all 15-year-olds with untreated caries.

Presence of sealants is a robust measure of past access to dental

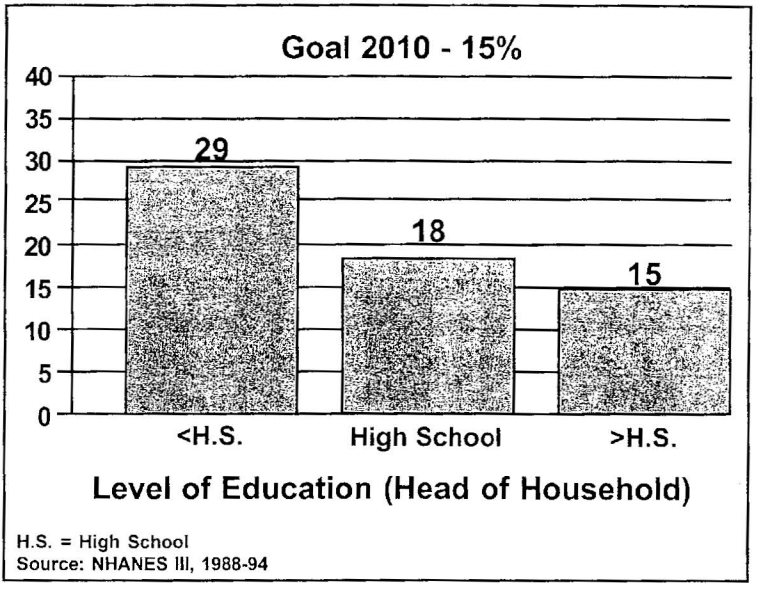


FIG. 2. Percentage of children age 15 who have untreated tooth decay.

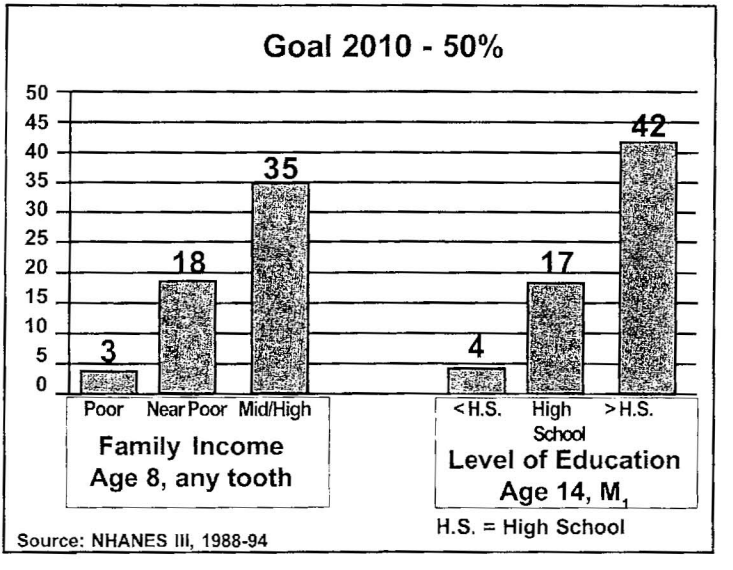


FIG. 3. Percentage of children with at least one dental sealant.

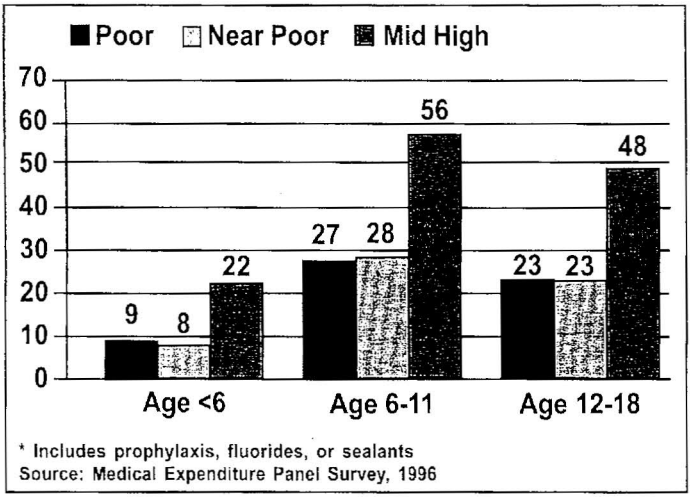


FIG. 4. Percentage of children with a preventive dental visit in past year by age and family income (visit includes prophylaxis, fluorides or sealants).

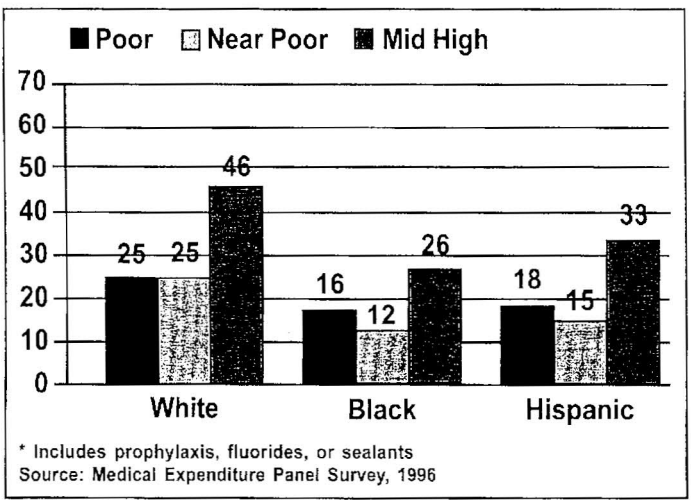


FIG. 5. Percentage of children ages 0-18 with a preventive dental visit in past year by race/ethnicity and family income (visit includes prophylaxis, fluorides or sealants).

prevention. In figure 3 this measure is arranged in two ways: on the left by family income level for children aged 8, and on the right by level of educational attainment of head of household for children aged 14. There is an unmistakable relationship of access to sealants to these two measures of socioeconomic status. The Goal for 2010 is 50% of children with sealants, the same non-attained goal for Healthy People 2000.

Figure 4 considers access to prevention more comprehensively including prophylaxis, topical fluorides and sealants, for three age groups—preschool children, elementary school children, and teens, by family income. The disparities in access to caries prevention are very evident. Yet even in the mid- to high-income families only half the children had a preventive dental visit in the past year.

Access to prevention in the past year for all children can also be assessed by race/ethnicity (fig. 5). Improved attendance with family income is again apparent and this is so for Whites, African-Americans and Hispanic Mexican Americans. But there is disparity between Whites at any income level, versus Blacks and Hispanics, in annual access to preventive dental visits.

The prevalence of untreated tooth decay (DT) in younger adults (35-

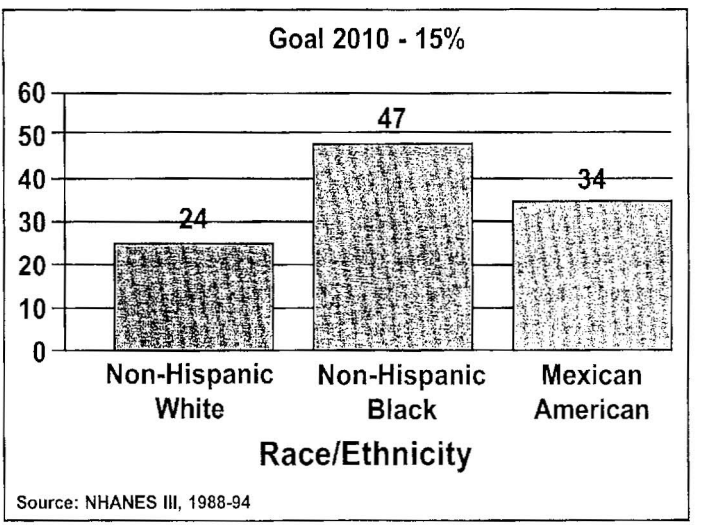
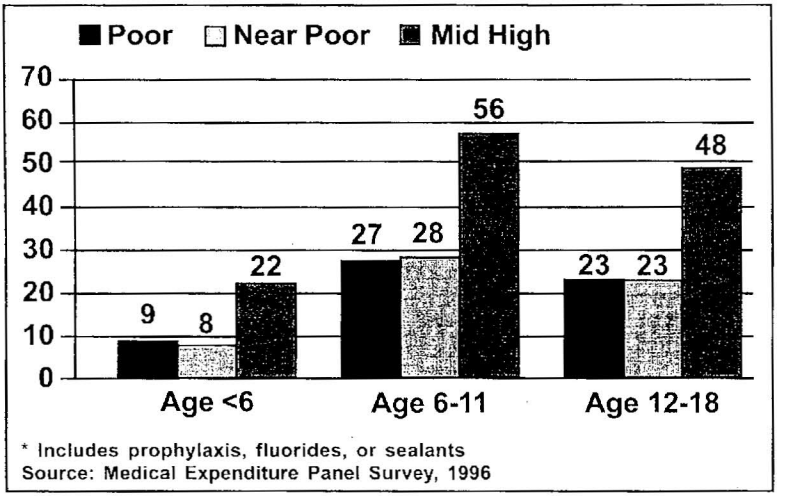


FIG. 6. Percentage of adults ages 35-44 years with tooth decay.



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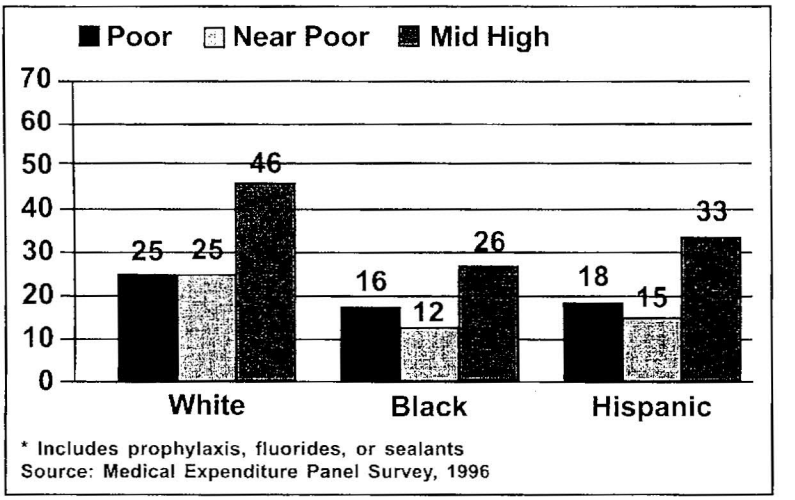

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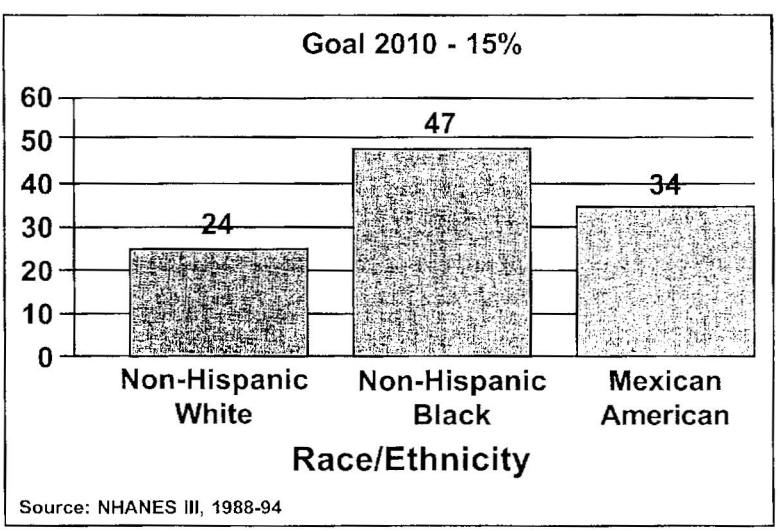

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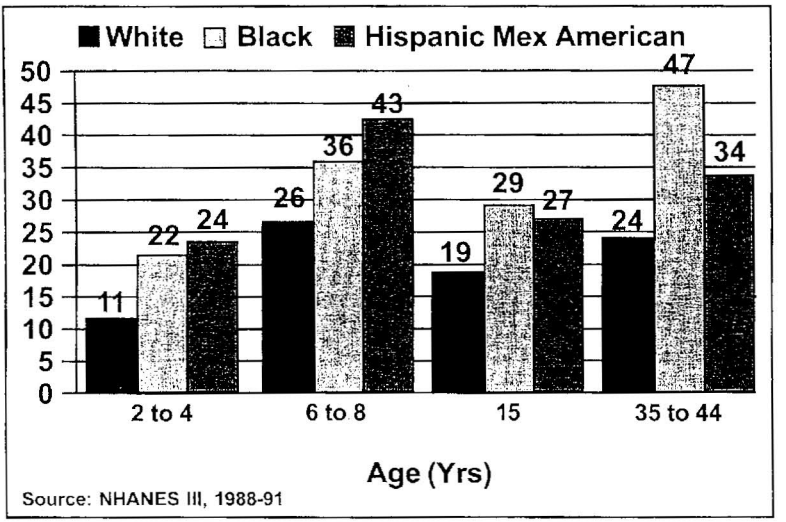

FIG. 7. Percentage of persons who have untreated coronal tooth decay by age and race ethnicity.

44 years) by race/ethnicity is shown in figure 6, with Whites lower than Mexican Americans who were lower than Blacks. The goal set for 2010 is that no more than 15% of young adults have untreated caries.

It's instructive to consider untreated dental caries by age and race/ethnicity (fig. 7). In every case Whites have a lower prevalence of DT. Blacks are intermediate in childhood, but not in adolescence and young adulthood. At ages 6-8, and considering primary and permanent teeth combined, the burden of caries is greater than at any other age. It had been shown by Stookey and others that, with the fluoride generation, caries not only decreased but was spread over the life span to a greater degree. It is apparent from figure 7 that in the U.S. population, the greatest burden still occurs in childhood. Blacks are an exception. A similar relationship was recently seen in a Texas statewide study where second-graders had a greater overall burden of caries in primary and permanent teeth than eighth graders [Brown et al., 1999].

Another way to consider need for restorative treatment is to review the degree of incompleteness of treatment (DS/DFS) by race/ethnicity in

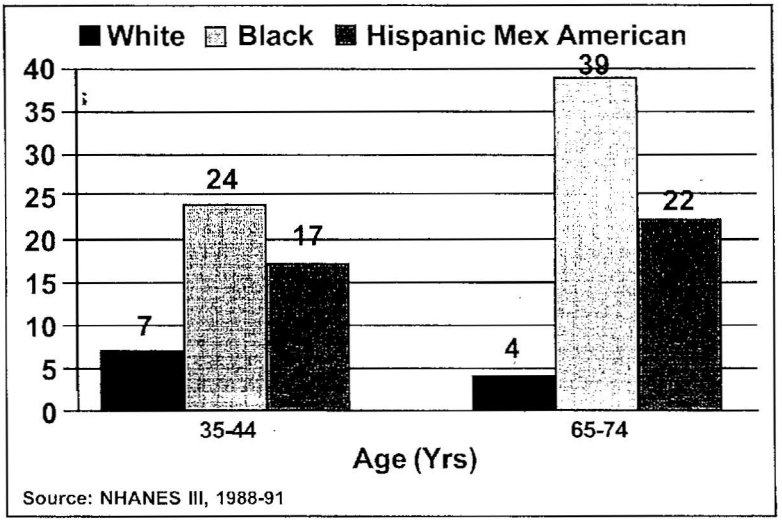

FIG. 8. Percentage of decayed and filled coronal surfaces which are decayed (DS/DFS%) by race/ethnicity.

	Percentage		
	White	Black	Hispanic Mex Am
Sound	53	60	54
Defective Intracoronal Restoration	31	17	18
Defective Crown/Bridge	6.7	2.9	4.1
Gross Loss of Tooth Structure Assoc with Restoration	5.0	1.9	2.1
Pulpal Involvement	1.5	3.6	6.6
Retained Roots	2.9	14.9	15.1

Source: NHANES III, 1988-91

FIG. 9. Unadjusted percentage of adults ages 55-74 years with highest restoration and tooth condition assessment (RTC) by race/ethnicity.

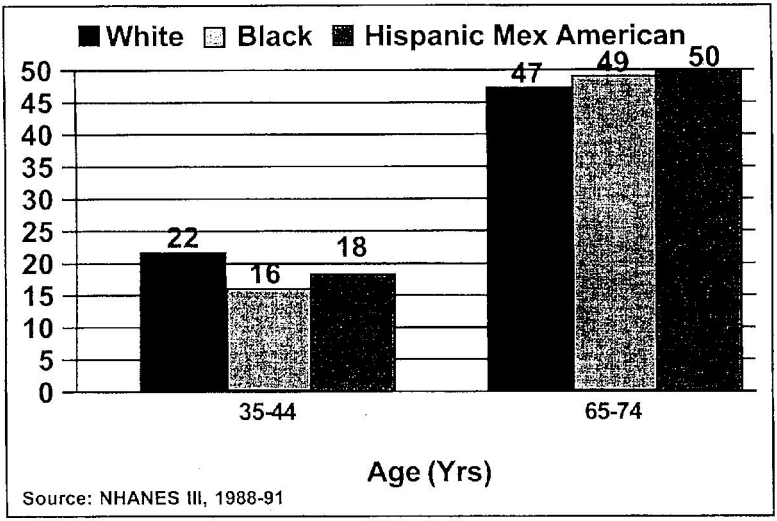

FIG. 10. Percentage of dentate adults with decayed or filled root surfaces by race/ethnicity.

younger and older adults (fig. 8). Incompleteness of restorative treatment for caries is clearly lower for Whites, intermediate for Mexican Americans and greatest for Blacks in each age group.

The NHANES III study included measures of defective restorations and stages of unrestored caries. These were referred to as Restoration and Tooth Conditions (RTC) assessments (fig. 9). Here RTC's are shown for the percent of persons with the most severe condition by race/ethnicity. The columns add to 100%. In Whites, defective intracoronal restorations, defective crowns/bridge elements and fractured restored teeth predominate. These are measures of iatrogenesis and of the present limits of restorative treatment. Pulpal involvement and retained roots, which are measures of failure to restore and prevent caries, predominate in Blacks and Mexican Americans.

Root caries prevalence in younger and older adults (fig. 10) varies little by race/ethnicity, though completeness of restoration of root caries is expected to vary with access to care.

Access to dental care in younger adults varies with education (fig. 11). The goal for 2010 is that 83% of all younger adults have a yearly dental

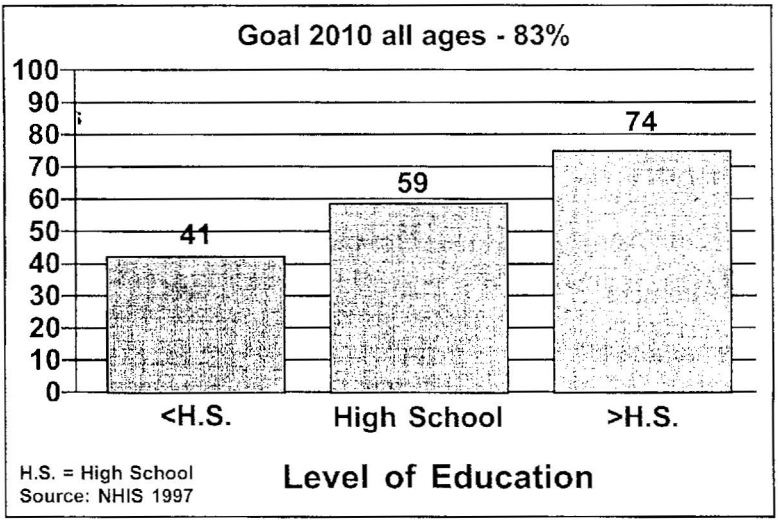

FIG. 11. Percentage of adults age 35+ who reported a past year dental visit.

visit. Across the U.S. there is considerable variability in annual dental attendance (fig. 12), but the pattern is not clear-cut.

In the three racial/ethnic groups shown in figure 13, annual dental attendance is higher in middle aged adults compared with the youngest adults

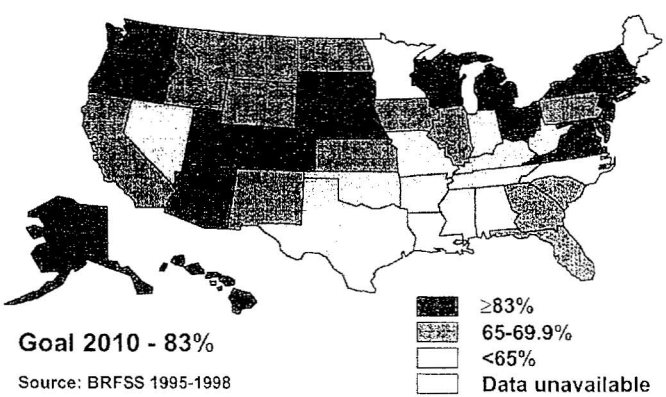

FIG. 12. Dental visits in past year for adults age 35+ (1995-1998).

	Percentage				
	White	Black	Hispanic Mex Am	All	Target 2
18+ years	52	37	40	--	83
35+ years	64	53	47	--	83
65+ dentate	--	--	--	55	83
65+ edentate	--	--	--	34	83
In long term care facilities				19	25

Source: NHANES III, 1988-91

FIG. 13. Dental visit in past year—percentage of adults.

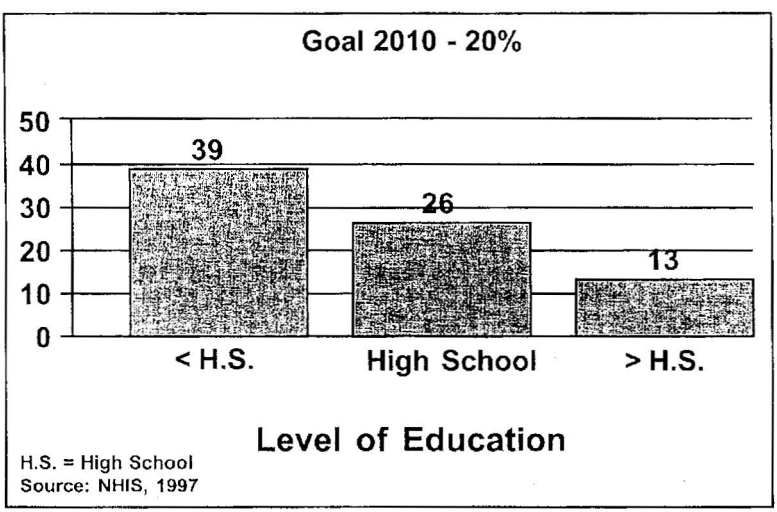

FIG. 14. Percentage of adults age 65+ with complete tooth loss.

and seniors 65+ years. It is considerably lower in edentate seniors, and lowest of all in adults in long-term care facilities for whom the Goal for Health 2010 is 25% compared with the present 19% having an annual dental visit. The target for adults generally is that 83% have an annual dental visit.

The prevalence of edentulousness in seniors aged 65+ varies with educational attainment (fig. 14). The Goal for 2010 is 20% overall. This seems to be an attainable goal and will itself be responsible for increased need for restorative dentistry due to caries and retreatment, even without considering increased longevity in the coming decade.

The U.S. geographic pattern of edentulousness after age 64 (fig. 15) resembles Dunnings World War I and II U.S. mapping of caries rank in military personnel [Dunning, 1986]. Younger adults, those presently under age 45 who are the fluoride generation, show a markedly lower rate of tooth loss and caries.

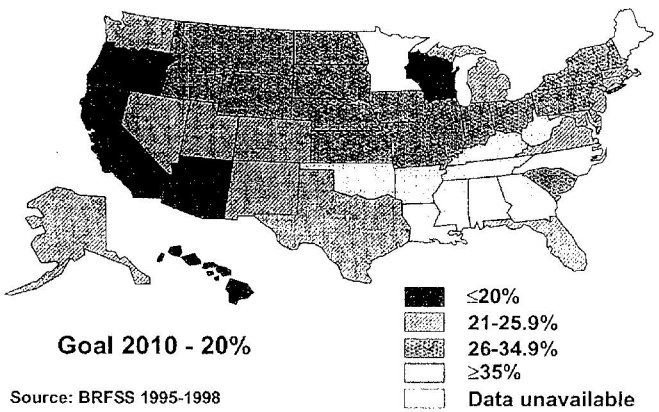

FIG. 15. Total tooth loss adults age 65+ (1995-1998).

One third of Whites 35-44 years have lost no teeth (fig. 16), with Mexican Americans and Blacks showing disparity in this respect. By 2010 it is planned that 42% of young adults will have lost no teeth. For older adults a quarter of Whites and Mexican Americans are edentate, and almost a third of Blacks (fig. 16). In the San Antonio site for the ICS II study Mexican

	Percentage		
	White	Black	Mex. Am.
35-44 No Tooth Loss	34	12	23
Goal 2010	42	42	42
65-74 Edentate	25	30	24
Goal 2010	20	20	20

NHANES III 1998-91

FIG. 16. Tooth loss—percentage of adults.

Americans, with significantly lower dental attendance, lower rate of caries treatment, lower rate of preventive dental attendance and a three-fold greater

	O.R.	99% Confidence Interval
Blacks vs. Whites, 18+ years		
■ Untreated Root Decay - adj for S.E.S. and recent dental visit	1.6	NS
■ RTC involving pulpal pathology or retained root - adj for S.E.S. and recent dental visit	2.2	***
Whites vs. Mexican Americans		
■ Recent Dental Visit (59 vs. 34%) - adj for age, gender, S.E.S.	1.5	***

Website: Research Reports on Oral Health Disparities under <http://www.nidcr.nih.gov/opportunities>

FIG. 17. Adjusted odds ratio (O.R.) for indicators of unmet oral health needs for specific subpopulations (U.S. 1988-94, HANES III).

rate of non-insulin dependent diabetes with its implications for destructive periodontitis, were no more likely to be edentulous than Whites.

Multivariate Relationships of Need for Restorative and Preventive Care

Figures 17, 18 and 19 show some examples of disparate oral health status and treatment needs which are of restorative and preventive importance, after controlling for demographic and health behavioral factors.

Untreated root decay does not differ significantly between Black and White adults after controlling simultaneously for SES and recent dental visit (fig. 17). But Restorative Treatment Conditions (RTC's) involving pulpal pathology or retained roots did occur twice as often in Blacks than Whites after simultaneous control for SES and recent dental visit (Odds Ratio [OR] 2.2, Confidence Interval [CI] 99%). Whites (59%) were one and a half times more likely to have a recent dental visit, after simultaneously controlling for age, gender and SES, than were Mexican Americans (34%).

In figure 18 dentate adults of lower versus higher SES are considered. After controlling simultaneously for age, gender, race/ethnicity, and

Lower SES vs. Higher SES for dentate persons 18+ years

	O.R.	99%
■ Untreated Coronal Decay - adj for age, gender, race/ethnicity, dental visit past year	4.9	***
■ Untreated Root Decay - adj for age, gender, race/ethnicity, dental visit past year	5.8	***
■ RTC involving pulpal pathology or retained root - adj for age, gender, race/ethnicity, dental visit past year	5.8	***
■ Visiting DDS or RDH Past Year - adj for age, gender, race/ethnicity	3.8	***

Website: Research Reports on Oral Health Disparities under <http://www.nidcr.nih.gov/opportunities>

FIG. 18. Adjusted odds ratio (O.R.) for indicators of unmet oral health needs by socioeconomic status (SES) [U.S. 1988-94, HANES III]

- **Being Hispanic was a significant factor for a low rate of caries treatment (F/DFT) in addition to income and education.**
- **Being Hispanic was a significant factor for lower dental attendance in addition to age, income, and education.**

It's not so much higher caries prevalence, but lower caries treatment which characterized Mexican Americans.

- **Caries, it's degree of treatment and dental attendance were not significantly related to acculturation or structural assimilation (Hazuda scales).**

(International Collaborative Study of Oral Health Outcomes, San Antonio Site. WHO 9/94)

FIG. 19. Modeling oral health outcomes for younger and older adults in San Antonio, Texas.

dental visit in the past year those of lower SES were:

i. Almost five times as likely to have untreated coronal decay,

ii. Almost six times as likely to have untreated root decay,

iii. Almost six times as likely to have restorative tooth conditions involving pulpal pathology and retained roots, and

iv. Almost four times less likely to have visited a dental professional in the past year.

Previously unpublished results from the ICS II San Antonio site for younger and older adults, summarized in figure 19, include the following disparities between Whites and Mexican Americans:

i. Being Mexican American was a significant factor for lower rate of caries treatment (F/DFT), after controlling for income and education.

ii. Being Mexican American was a significant factor for lower dental attendance, after controlling for age, income and education. Lower caries treatment and access to treatment, more than higher caries rate, characterize these Hispanic adults.

iii. Caries, its degree of treatment and dental attendance were not significantly related to acculturation or structural assimilation of Mexican Americans, using the validated scales of Hazuda et al. [1988]. Acculturation refers to the various axes of transition between two cultures. This implies

that provided oral health education and health promotion appropriate to culture and language are available, adoption of specific preventive approaches for the various axes and stages of transition from Mexican to American culture (acculturation) is not likely to be of additional value in influencing oral health outcomes and behaviors.

Finally, caries, its degree of treatment and dental attendance were significantly related to income, education, age, gender, knowledge of oral disease and of its prevention, personal health behaviors, self perception of oral function and status. Other studies have shown that maternal preventive behaviors and fear or anxiety about dental care are also related to caries, its treatment and access to care. But the most influential barrier to oral health found in the ICS II Study in San Antonio, as indicated by the degree of variance explained, was cost of dental care.

Conclusion

Restorative and preventive dentistry as discussed are a part of primary health care, and essential in attaining overall health. These functions are almost entirely in the realm of dentists and dental hygienists, and not of other health professionals. Under the ethical principle of justice, it is to be claimed that some agreed minimum of health care is a right for all members of a society. In the U.S., it is argued, this minimum includes primary health care, which in turn includes basic preventive, restorative and emergency dental services, as well as certain health education and health promotional programs organized at the community level.

Likewise, it is an ethical responsibility to test, apply and translate to practice explanatory hypotheses of and solutions to disparities in oral health. Such dental health services research studies will inevitably challenge some long-held and unquestioned assumptions about dental treatment, oral health promotion, health behaviors, and ethical values in dentistry. That is an uncomfortable but necessary part of scientific inquiry and ethical problem-solving. Oral health disparities are our challenge and our responsibility.

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Caries Risk Assessment and Restorative Treatment

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As we move from the 20th into the 21st century, we are moving further away from the pioneering dentistry of Miller and Black, and as a result there are fundamental alterations in the way that restorative dental treatment is and will be applied. Contributing to this paradigm shift are an increased knowledge of the etiology, natural history, progression and prevention of caries, along with improvements in the diagnostic armamentarium, new restorative materials and techniques. When these factors are combined with the decreased prevalence of caries, alterations in its incidence (rate of attack), changes in the demographics of the population at large (an increase in the elderly population), as well as increased prevalence of polypharmacy, it becomes increasingly evident that the traditional philosophy of excellence in restorative dentistry requires an update. It is also apparent that caries patterns are polarized in the population, with a small percentage having the greatest burden of disease. Identification of these patients is key to successful long-term maintenance of both their oral health and their existing or new restorations. Practitioners are encountering increased demands for complicated and expensive treatment options, such as implants and aesthetic dentistry. Premature failure of highly involved and expensive restorative treatment plans may occur if the issue of the fundamental etiology of the disease underlying the need for such treatment is not addressed. Most practitioners recognize that it would be foolhardy to provide a patient with a fixed partial prosthesis or overdenture without ensuring that the patient can maintain effective oral hygiene. However, how often are patients sent home with a mouthful of temporary crowns without consideration given to their dietary habits? We therefore propose routine adoption of a risk-based assessment of caries activity (CRA—Caries Risk Assessment) prior to the initiation of the treatment phase of any proposed restorative therapy.

A recent Medline search of the term "Caries risk assessment" revealed 192 references, of which all but 14 have been since 1990. Although many of these papers and reviews do not directly address the term as it will be used in this paper, it is clear that this form of risk assessment has gained credibility and importance over a relatively short period of time. One of the earliest and most influential advocates of caries risk assessment (CRA) as a clinical, rather than a research, tool was Bo Krasse, whose classic monograph "Caries Risk—a Practical Guide for Assessment and Control," was published in 1985 [Krasse]. The methods described in this treatise are practical and applicable to chairside risk assessment. Pertinent clinical and laboratory factors (stimulated whole saliva flow rate and buffer capacity; salivary mutans streptococci counts; diet evaluation) are combined to establish a generalized risk profile of the patient, which further goes on to suggest appropriate preventive therapies, counseling and restorative treatment as required. Until relatively recently, this type of practical, etiologic- and preventive-based approach was considered to be more a European than North American style of dentistry. In North America, restorative dentistry has traditionally focused on treating, or repairing the tissue damage, not in prevention of the infection or appropriate risk management to lower future risk of tissue damage. However, a multiplicity of factors including changes in population demographics, caries prevalence, diagnostic and restorative techniques, healthcare financing, and last, but not least, patient expectations, have all contributed to a movement toward a more preventive-minded approach to dental treatment on this side of the Atlantic. A rational process of determining caries risk from specific etiologic factors would naturally lead the clinician and the patient towards a regimen of preventive care aimed at lowering those risk factors, such that the likelihood of premature failure of any planned extensive restorative treatment would be lessened.

Earlier publications on caries risk often focused on prediction of future caries as the end-point. For example, at a 1989 conference on Risk Assessment in Dentistry, the application of behavioral and sociodemographic [Hunt, 1990], physical and environmental [Graves et al., 1990], and microbiological and salivary [Krasse, 1990] risk factors on caries prediction were all reviewed in some detail. From an epidemiological perspective, studies from North Carolina and Rochester attempted to identify risk factors in prospective trials, utilizing sophisticated statistical techniques such as logistic

multiple regression models and multiple linear discriminant analysis [Beck et al., 1992; Disney et al., 1990, 1992; Graves et al., 1991; Leverett et al., 1993a,b; Stamm et al., 1993, 1988]. These studies have provided much useful information on risk factors at the population level, and many of these findings have been incorporated into CRA systems.

More recently, there has been a return towards the idea of applied caries risk assessment that was advocated by Krasse, i.e., as a tool for the practitioner at the level of the dentist-to-patient relationship. A step towards this was the inclusion of CRA in the late 1980s in the clinics at the UTHSCSA Dental School [Dodds and Suddick, 1995], which seemed to stimulate broader interest in dental educational clinical settings. A recent survey of U.S. dental schools revealed that 34 of 42 responding schools reported having a formal training program in CRA [Yorty and Brown, 1999]. Sixteen of these, or 38% of the responding schools, claimed to categorize patients as low, moderate or high risk. Earlier publications have detailed specific CRA programs at various schools [Brown, 1995; Burgess, 1995; Dodds and Suddick, 1995; Hildebrandt, 1995; Stoddard, 1995; Suddick and Dodds, 1997]; thus recent and new dental graduates have a reasonable exposure to the topic. How this undergraduate exposure translates into real-world experience in private practice is unclear; despite the greater acceptance of managed care programs and the cost benefits of prevention versus cure in dentistry, insurance providers have been notoriously tardy in embracing prevention for all patients, beyond a yearly prophylaxis. However, there is no doubt that the word is getting out, and a number of excellent publications have provided practical advice on incorporating CRA into routine dental practice [Anusavice, 1995; Kidd, 1998, 1999; Powell, 1998].

The purpose of this paper is to describe a framework for CRA within the context of an approach to risk assessment, diagnosis and treatment planning, and execution, such that the outcome is based on the principles of good outcomes and best practices. We will also attempt to define the terms "caries activity" and "caries risk" and to clarify the relationships between them as they are applied to CRA. Finally, as an example of an implementation of CRA, we will describe in general terms the latest iteration of the San Antonio CRA (SACRA).

Caries Activity, Caries Risk and CRA Defined

Caries activity is defined as occurring whenever a plaque deposit on a tooth surface is causing demineralization in the underlying enamel; caries risk is the probability that caries activity will result in a clinical lesion within a defined time period (e.g., one year). CRA is further defined as a systematic process based on the patient's past and present patterns of caries (caries activity), and known disease etiology that attempts to categorize patients into "at risk" or "not at risk" groups with respect to development of new caries lesions within a defined time period. Clearly caries activity and caries risk are not synonymous. SACRA is an algorithm that weights these factors in a definite manner that has been in effect since the late 1980s at the UTHSCSA Dental School [Dodds and Suddick, 1995; Suddick and Dodds, 1997].

Determination of caries activity can be problematic. Given the caries continuum, from enamel white spots to open cavities it is often difficult from a single examination to determine whether a caries lesion is dynamically active, arrested, or in a phase of remineralization. Traditional diagnostic aids such as radiographs or fiber-optic transillumination (FOTI) offer little or no help regarding dynamics; these tools aid us only in assessing the present stage of the lesion with respect to the degree of loss of mineral in subsurface layers [Pitts, 1997; Wenzel, 1993]. Thus the only sure way to assess the activity dynamics of individual lesions is by longitudinal observation and comparison of radiographs or other measurable and recorded representations of the status of the lesion.

Any CRA system is likely to start with the known etiologic factors that must in some way be condensed into a single dichotomous outcome variable of "at risk" or "not at risk." These factors may include (but are not limited to) past and present caries activity, dietary sugar consumption, access to fluoride, salivary sufficiency (adequacy of output with respect to flow and composition), the presence of cariogenic microorganisms, etc. Other factors that could be considered include age, socio-economic status, and medical history. Clearly it would not feasible to incorporate all known risk factors into a single CRA system that could reasonably be applied to all patients routinely. For that reason, we use the terms *indicators* and *co-indicators* to define aspects of a CRA system that, based on the epidemiological caries-predictive literature and the known pathobiology of the caries pro-

cess, would be most useful within a CRA. *Indicators* are the findings from the clinical examination pertaining to obvious caries lesions, including number, severity, surfaces involved and *apparent* activity (i.e., progressing or arrested/remineralizing). Accurate diagnosis of early enamel (incipient) caries is a requirement for this type of clinical assessment, and this is still known to be problematic [Pitts, 1997]. When this is combined with the dilemmas involved in determining the stage of activity of such lesions, it is apparent that additional information is needed for this type of determination. *Co-indicators* are caries etiologic findings or other modifying factors, including but not limited to, a non-favorable pattern of consumption of cariogenic food items, the presence of high concentrations of cariogenic bacteria in the oral cavity, salivary hypofunction, and the period of time since dental treatment for caries was last sought. Selection of appropriate co-indicators to be used in a CRA system depends both on their value as predictive factors as well as their ease of use and utility in a dental clinical setting.

Caries Risk as a Dichotomous Variable

As was indicated earlier, the ideal CRA outcome would be either "at risk" or "not at risk." However, prospective studies of caries development from the classic early work of Backer Dirks [1966] to more recent summaries of the literature [Pine and ten Bosch, 1996] suggest that, at least in population studies, risk is a continuous variable. For example, Backer Dirks [1966] showed that 63 out of 72 specific white spot lesions in lower first molars were either arrested or remineralized after 7 years, indicating a probability of 12.5% ($p = 0.125$) of an initial (incipient) lesion progressing. In a recent review of 13 longitudinal caries studies, the rate of progression was clearly related to the extent of demineralization as well as the site of the lesions at onset, implying a continuously varying risk of progression for individual lesions [Pine and ten Bosch, 1996]. We suggest that caries risk must be viewed as a continuous variable whenever risk is defined on an open-ended time line, but in a CRA system one may choose to define a time period after the first caries risk assessment in order to force a judgment of high or low risk.

CRA in the Context of Patient Management

The general model of how CRA might fit into an overall patient management schema is presented in figures 1-3. Figure 1 shows how caries activity, caries risk and patient management are related in a simple model; figure 2 expands the preceding model to include other determinants of caries risk, and how the effect of a preventive plan appropriately incorporated into, and integrated with, the restorative plan can result in an improvement in the patient's risk profile and expectations at the time of re-evaluation.

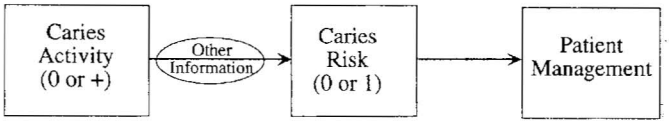

FIG. 1. Relationship between caries activity and caries risk. Caries activity is defined as persisting net demineralization occurring in the enamel under a plaque deposit. There are four possible activity scores: 0 (no activity in the mouth); + (one active site); 2 + (two active sites); and 3+ (more than two active sites).

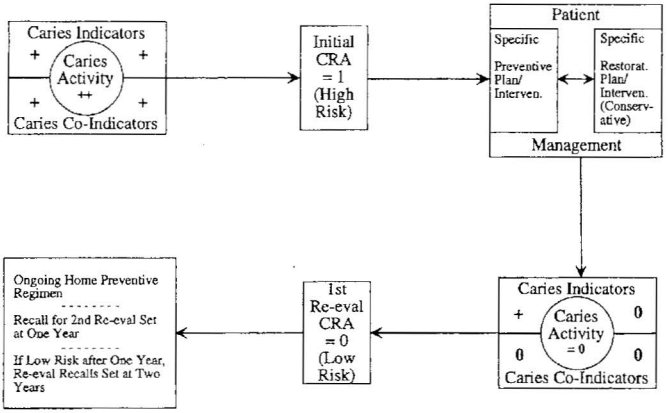

FIG. 2. Effects of caries activity indicators/co-indicators on the caries risk assessment (CRA) and patient management with feedback to reduce activity and risk. This figure shows the relationships between caries activity, expressed as indicators and co-indicators, on the caries risk assessment (High risk) and the CRA-induced effect on patient management; the feedback loss extends back from the positive benefits of the CRA on patient management to reduce caries activity and to lower the risk (to 0) at the time of re-evaluation of the CRA.

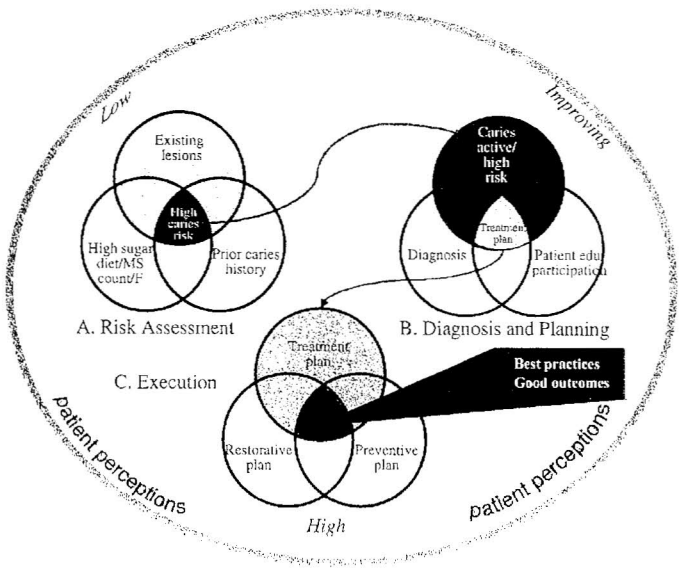

FIG. 3. CRA and patient management. This model conceptualizes the CRA/patient management model in the form of a three-step process (risk assessment, diagnosis and planning, and execution); using the caries etiology Venn diagram as a recurring motif, the outcome of each step (central overlapping area) becomes a factor included in the next step. Assuming high risk at the onset, the model is superimposed on a background of patient perceptions of oral health and consequent behaviors that improve with progression through the stages, resulting in the idealized outcome.

Finally, figure 3 is a representation of the CRA process as it relates to the three steps of risk assessment, treatment planning, and treatment plan execution.

Specifics of the San Antonio Caries Risk Assessment (SACRA) Method

The SACRA method provides three broad risk estimates: Low, Moderate, and High. This categorization, and the fact that each estimate rests on a range of CRA numerical scores, appears to imply to the clinician and the patient that caries risk is a continuous variable. As has been explained, this is not the case, since the risk rating applies for a limited time frame. The

SACRA method considers caries risk to be a dichotomous variable, either Low or High within the framework of a period of one year following the assessment [Suddick and Dodds, 1997]. The Moderate rating is assigned *only when the final CRA score indicates that risk cannot be assigned to low or high for the year following the assessment.* Whenever the Moderate status is assigned, caries risk for that patient is a continuous variable until a Low or High ranking can be assigned. Thus, for Moderate category patients, the CRA re-evaluation recall interval is set at six months, versus 12 months for the low risk patient, and three months for the high risk patient. In effect, the Moderate rating suggests that the probability of new caries for the year following the assessment may be as low as 20% or as high as 80%. Therefore, a prudent and appropriate preventive intervention plan should be utilized until a CRA re-evaluation can be carried out about six months following the assignment of the Moderate rating.

The SACRA started with an algorithm developed by one of us (© R.P. Suddick 1989), which was utilized in the school clinics, essentially unchanged, for two years. The initial CRA algorithm and preventive system has been subsequently refined by the UTHSCSA Department of Community Dentistry, bringing it to its current status. Figure 4 shows the actual forms being used by the dental students at UTHSCSA. The clinical activity required of the students is known as the Oral Health Evaluation (or OHE) of which the CRA is the initial component. Clinical faculty have supervised dental students in carrying out CRAs on thousands of patients in the teaching clinics, and participate in an annual review session devoted to refining the system based on analysis of its use in the clinics. These individuals represent a consensus panel of experts for the SACRA expert system.

CRA Algorithm and Procedure

The algorithm for the SACRA contains the following data elements, weighted and scored as specified: (1) frank carious lesions present, weight 3; (2) each lesion score in addition, weight 1 each; (3) incipient (enamel) lesions (with intact surface contour or topology), weight 1 each; (4) five or more filled surfaces, weight 2; (5) one or more teeth missing due to caries; weight 2; (6) inadequate exposure to fluoride, systemic and topical, weight 1 or 2; and (7) diet screening for high sugar, weight 0-7. In addition to these

Patient Name ____________________ Age ________ Patient Number __________

Student Name ____________________ Student Number ______________

Oral Health Reevaluation

Note: If patient is edentulous, reevaluation does not apply.

	CARIES RISK ASSESSMENT			
	Dietary screening for caries risk	**Dates →**		
1	Do you eat food or drink beverages five or more times a day?	1 pt if yes		
2	Do you chew regular (non-sugar-free) gum?	1 pt if yes		
3	Do you drink any sweetened beverages between meals?	2 pts if yes		
4	Do you eat mints, candies, pastries, chips, crackers, etc., between meals?	2 pts if yes		
5	Do you drink milk or eat cheese every day?	1 pt if no		
	Dietary screening total			
	Caries activity - consider clinical and radiographic findings			
6	Carious lesions present?	3 pts if yes		
7	Number of carious lesions present on coronal/exposed root surfaces:	1 pt each		
8	Number of carious lesions limited to enamel (incipient):	1 pt each		
9	Five or more filled surfaces (amalgams, composites, crowns)?	2 pts if yes		
10	One or more teeth missing due to caries?	2 pts if yes		
	Caries activity total			
	Fluoride exposure			
11	No fluoride from water, tablets or drops?	1 pt		
12	No fluoride from toothpaste, rinse or gel?	1 pt		
	Caries Risk Assessment Total (#1-12)			
	Caries Risk Category (Very High, High, Moderate, Low)			

	Prior Dietary Evaluation: ❑ 24-hour ❑ 3-day ❑ None			
13	Was diet found to be caries-promoting?	Y/N		
14	What were the most prevailing caries-promoting factors? ❑ Soda or other sweetened beverages ❑ Starchy processed snack foods ❑ Sweet processed snack foods ❑ Patterns of eating ❑ Absence of cariostatic foods (dairy products, sugar substitute products) ❑ Others______			
15	Is patient compliant with dietary recommendations?	Y/N		
16	Are further dietary recommendations needed? If yes, make a chart note.	Y/N		

	OTHER ORAL HEALTH RISK FACTORS AT REEVALUATION			
17	Poor oral hygiene? Rescore if originally ≥20%	Y/N		
18	Low saliva flow rate? Retest if originally ≤.2ml/min. (unstimulated)	Y/N		
19	Mutans streptococci count high? Retest if originally >5.5x10^5 cfu/ml	Y/N		
20	Oral cancer risk factors? (alcohol, tobacco, sunlight, history of oral cancer)	Y/N		
21	Risk of oral injury? (contact sport, no seatbelt use, physical abuse)	Y/N		

M. strep count: 1st - ______cfu/ml Current - ______cfu/ml Saliva flow rate: 1st test - ______ml/min Current - ______ml/min

If prevention is to be changed or Preventive Behaviors reinforced, refer to the original Preventive Plan Guide and enter changes on the Prevention and Treatment Plan Additions Form, and below. Add (+) Delete (-) Substitute (=)

Change Code (+ /- / =)	Phase	ADA Code	Tooth/Surface	Description

Faculty sig. (Eval.) ______________ Faculty ID ______________ Date ______________

Faculty sig. (Reeval.) ______________ Faculty ID ______________ Date ______________

FIG. 4. The San Antonio Caries Risk Assessment (SACRA). A copy of the CRA/Oral Health Evaluation form in use at the UTHSCSA Dental School.

seven items, saliva tests for inadequate flow rate and mutans streptococci colony counts (cfu/ml) are done whenever the CRA score summed from these data elements suggests high risk, high sugar diet, or if caries lesions are present. If the CRA score indicates borderline risk, an abnormally low unstimulated flow rate or a high MS count (5.5×10^5 cfu/ml or greater) will usually result in moving the patient's risk category to the next higher level.

All of the above is contained in a format that permits an easy-to-do check-off tally during the initial exam. A final score of 4 or less indicates low caries risk, a score of 10 to 15 suggests high caries risk, and scores of 5 through 9 are marked as moderate risk. Patients will be assessed as "very high risk" if the CRA score is above 15. The high/very high risk ratings indicates that the patient should be treated with a set of preventive interventions that are intended to bring the infectious caries process under control, and to prevent a new attack of the disease process; these patients are also scheduled for a CRA re-evaluation at three months following the initial assessment. The moderate risk patients are usually prescribed the same set of preventive interventions as the high risk patients, but their CRA re-evaluation is scheduled six months following the initial assessment. The patients who are assessed to be at low risk for caries generally do not receive any preventive interventions other than reinforcing and encouraging them to continue good oral health practices. If the low risk patient is young (< 2 years) and living in a non-fluoridated community, it would not be unreasonable to prescribe a professional fluoride treatment. These low-risk patients are scheduled for a CRA re-evaluation 12 months following this initial assessment.

Salivary Tests as Co-Indicators

In general terms, co-indicators of caries should satisfy certain criteria; they should measure factors related to caries, offer technical simplicity, produce rapid results, cause minimal false responses (false positives preferable to false negatives), show a consistent correlation with disease activity, and have high reliability and validity (i.e., be accurate and reproducible). A categorical example is salivary co-indicators. Salivary co-indicator laboratory tests may include measurements of the physicochemical properties of saliva (flow rates, buffer capacity) or measurements of its specific cariogenic

pathogen carriage (e.g., mutans streptococci [MS] tests), as examples. A simple clinical test is the measurement of unstimulated flow rate.

Salivary tests may be useful in specific cases and, as such, should be applied to selected patients during the caries risk assessment. They should not be used as a general screening tool, particularly since the cost:benefit ratio of such tests may be high. Many of these tests used in isolation have frequent false positive (low specificity) or false negative (low sensitivity) findings. The salivary lab tests are usually best applied to patients with several active clinical or incipient caries lesions to help elucidate the presumed cause of their high caries activity and risk, thus leading to a targeted caries preventive plan or regimen. For instance, the salivary MS colony count tests are particularly helpful in demonstrating to the patient the consequence of a diet that is high in between-meals snacks of high sugar content and can be utilized to motivate the patient to change a harmful dietary pattern. The broad goal is to develop tools that can be used in an incremental fashion to aid the individual clinician in making appropriate judgments as to both caries risk status and an appropriate preventive intervention regimen in each patient. This approach includes taking adjunctive tests only when required to aid in these clinical judgments.

Risk-Based Prevention

One of the primary purposes of assessing caries risk is to utilize the level of risk of each patient as the basis for prescribing preventive interventions, as well as for vital background information for restorative dentistry, cosmetic dentistry, implants and so on. At the outset, it is obviously of utmost importance to utilize intensive preventive therapies for patients who are at high risk for new caries.

The SACRA methodology is very useful for the purpose of systematizing the application of an appropriate plan of prevention for each patient. There are a limited number of recognized, effective preventive modalities or interventions. Seven such modalities are recognized to be useful in conjunction with the SACRA method; these are listed here in a rank order that is based on the frequency that they are prescribed for the high caries risk patients. This list does not include prophylaxis and oral hygiene instructions that are prescribed, essentially indiscriminately, for all patients (a bow to

tradition). It is obvious that clinicians have two factors to consider in prescribing these interventions: effectiveness and ease of use.

Preventive Interventions (Modalities)

1. Professionally applied fluoride treatment (1.23% APF, fluoride varnish, neutral NaF gels or NaF varnish applicator)
2. Diet analysis and counseling
3. Adjunctive fluoride home care (rinses, NaF gel)
4. Sealants
5. Caries control (excavating gross dentinal decay and placing tem porary restorations)
6. Restorative therapy (preventive restorations)
7. Oral antimicrobial treatment (chlorhexidine)

Preventive Strategies Specific to Level of Risk

The following represents the most often used combinations of preventive interventions being prescribed in the clinics of the University of Texas Dental School at San Antonio in conjunction with the specified levels of caries risk as assessed by the SACRA. Please refer to the list of seven common preventive interventions above to view the specific interventions used at each risk level.

A. For high risk patients over 25 years of age in which the existing caries lesions are primarily located on smooth surfaces: apply interventions 1-3 above, plus interventions 4-7 individually as deemed appropriate; re-evaluate in 3 months.

B. For high risk patients less than 26 years of age, especially those in which the existing caries lesions are primarily pit and fissure lesions: apply interventions 1-4 above, plus interventions 5-7 individually, as deemed appropriate; re-evaluate in 3 months.

C. For very high risk patients (a sub-category of the high risk population in which there are 5 or more frank carious lesions): apply interventions 1-7.

D. For moderate risk patients: these patients should be treated essentially as high risk patients as far as specific interventions, i.e., at age 26 and

older, interventions 1-3 (or 4, on an individual basis), and at ages 25 and younger, interventions 1-4. In both instances interventions 5, 6, and 7 can also be prescribed individually when appropriate; re-evaluate in six months. As far as re-evaluations are concerned, at the time that any patient in the high or moderate risk categories is first re-evaluated, if the MS colony counts were high initially, then the saliva MS test is repeated. If MS counts are still high, then the diet queries or surveys, and counseling are repeated.

E. For low risk patients: generally, low caries risk patients do not need any preventive interventions other than re-enforcing good dental health practices and, in individual cases, brief counseling or educating on oral hygiene practices and products, and diet habits. These patients are re-evaluated after 12 months and if they are still at low risk, no further examination for caries or assessment for risk need be done for two years.

Validation Issues

The SACRA is designed to function entirely within the standard parameters of dental practice. It simply streams patients into the obvious categories of high and low risk for the purposes of efficient utilization of the personnel and material resources required for recognized preventive treatments or interventions. The model leads to a moderate risk rating whenever its application does not result in a clear high or low risk categorization. When the moderate category is the outcome, the model remains very conservative, since it calls for a CRA re-evaluation in six months, the traditional recall interval used in dentistry, and during which intensive preventive interventions have been prescribed. In short, the San Antonio CRA/Risk-based prevention model appears to have very high construct validity as a means of focusing dental material and personnel resources on those dental patients (in private practices) who are in greatest need of these procedures.

Summary and Conclusions

Based upon these facts, we make the following recommendations:

1. The limitations of the present diagnostic techniques and technologies do not allow the activity state and/or rate of progression of a lesion to be determined with confidence at a single examination time point. There-

fore, during the oral examination a clinical data set should be collected under a specific methodology that includes co-indicators of caries activity to aid in making an assessment of caries activity and caries risk for every patient.

2. Establishing the caries risk of a patient may greatly affect the course of treatment for that patient; therefore every patient should be assessed for caries risk.

3. The established dental care paradigm may require modification to allow longitudinal data collection and adjunctive acquisition of co-indicator data before irreversible treatment decisions are rendered.

4. For further validation and optimization of the SACRA, or any CRA system, a set of outcome parameters needs to be defined such that actual improvements in caries risk can be documented. The SACRA is presently undergoing such an evaluation, and we anticipate that modifications of the system may be needed in the light of this process.

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