Trends in Oral Diseases in the U.S. Population

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Abstract: This article reviews trends in dental caries, periodontal disease, and tooth loss for the United States along with population dynamics and risk factors that might influence these trends going forward. Dental caries experience remains high in the primary dentition. Caries severity in permanent teeth of children has declined to historically low levels, and long-standing inequalities in untreated caries appear to be narrowing. Declines in caries severity of children's permanent teeth have stabilized at a low level, but likely will contribute to future reductions in dental caries severity in adults. The prevalence of periodontal disease is high in adults, and only a small percentage have severe forms of the disease. Countervailing trends in determinants would suggest little change in the prevalence of periodontal disease in the future, but the lack of an obvious trend over the last two decades makes projections uncertain. Tooth loss as a consequence of dental disease has declined markedly over the last half century and has been all but eliminated in high-income groups. However, notable exceptions to these favorable trends are evident. Progress in prevention policies and programs that affect disease experience appears slower than progress in meeting population-level caries treatment needs. Clearly, long-standing inequities related to political and social determinants remain for all dental diseases, and income disparities in dental disease are widening for some indicators. Growing inequalities raise ethical and public health concerns that should be prominent in discussions of dental workforce needs and strategies for the next 25 years. This article was written as part of the project "Advancing Dental Education in the 21st Century."

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The prevalence and severity of oral conditions, their distribution in the population, and projected changes over time should be among the primary considerations in planning for the future of dentistry. In this article, we review population trends in dental caries, periodontal disease, and tooth loss over the last several decades using existing national data. We then consider these trends along with changes in social determinants and other risk factors that might influence the prevalence and distribution of these conditions in the future. Although challenging methodologically, use of a needs-based approach to workforce planning, even if approached qualitatively, is intuitively appealing.[1-4] This article was written as part of the project "Advancing Dental Education in the 21st Century."

The United States is undergoing a transformation in many of the social determinants known to influence population oral health.[5] Three sets of determinants are particularly relevant: demographic characteristics of the population, literacy levels, and the economy. The size of the population will continue to grow between now and 2040, but at a slower rate than the last few decades, increasing by 61.5 million people.[6] The population is getting older and more diverse. In 2040, those 65 years of age and older (22% of the total population) for the first time will outnumber those younger than 18 years of age (21%). First- and second-generation immigrants are projected to represent 33% of the population in 2040, with the majority being of Latino origin. By 2044, more than half of Americans are projected to belong to a minority group.

According to the Educational Testing Service, 52% of the U.S. population lacks literacy and numeracy skills needed to participate in an increasingly

complex and demanding society.[5] It projects that, by 2030, average literacy levels in the working-age population will have decreased by 5%. In addition, the economy has been restructured so that many adults are unable to participate fully in the workforce, a trend that leads to growing inequalities in income and wealth. An analysis of U.S. Census data by the Pew Research Center highlights the increasing polarization of incomes in America.[7] Between 1971 and 2015, the percentage of adults living in lower income households increased from 25% to 29% and those in higher income households increased from 14% to 21%, squeezing the middle income group, which fell from 61% to 50%. These sweeping changes in population demographics, literacy, and the economy are likely to continue and to interact in powerful ways to influence inequalities in oral health and well-being.[8,9]

Assessment of Oral Health Status in National Surveys

Where possible, we used published results of national surveys with clinical assessments of oral conditions as the primary source of information for this review.[10-16] These repeated, cross-sectional surveys, referred to since 1971 as the National Health and Nutrition Examination Survey (NHANES), provide comparable estimates for most oral health conditions for the overall population and for selected subgroups for roughly each decade starting with the 1960s. Published results for two other surveys conducted in the 1980s by the National Institutes of Health (NIH) also were considered in our analysis.[17,18]

The prevalence and severity of common oral conditions display a strong social gradient in most populations and across the lifespan.[19] Oral health indicators become progressively worse in a stepwise fashion as disadvantage increases.[20,21] We consider several inequalities in our review but concentrate primarily on income inequalities. We present estimates of inequality in outcomes as the absolute difference or ratio between the highest and lowest income groups for various survey years using methods suggested by the National Center for Health Statistics.[22,23]

Detailed information for the 2011-12 round of NHANES has not been published, so published sources provide limited insights into changes in oral health status between the beginning of the 2000s and the end of that decade. We therefore analyzed publicly available NHANES data files back to 1971-74 to examine changes in income disparities for dental caries, periodontal disease, and tooth loss and to ensure comparably defined subgroups.[24-27] The 2011-12 estimates for dental caries must be considered preliminary because they are based on only two years of survey data collection, whereas a minimum of four years is recommended by the National Center for Health Statistics. We include these estimates in our time trend analysis, however, to capture the potential impact of important interventions implemented since publication of the surgeon general's report in 2000 calling for broad-based attention to the high prevalence and stark disparities in oral diseases.[28]

Distribution of Oral Diseases and Trends

Dental Caries

Dental caries experience is reported in national surveys using various summary measures of counts of individual decayed, missing, and filled surfaces (DMFS) or teeth (DMFT). These assessments have used consistent examination methods, definitions, and diagnostic criteria for most years, so comparisons between surveys can be made to determine time trends, particularly in children and young adults. However, epidemiologic assessments of dental caries using the index of DMFT is more challenging in adults than in children because the "missing-tooth" component makes a greater contribution in successively older age groups. Many teeth are extracted for reasons other than dental caries, and thus the index becomes less accurate as a measure of dental caries experience. Nevertheless, counts of DMFT, either as individual components or combined, provide valuable insights into population oral health.

Dental caries in the primary dentition. Small and inconsistent changes in the prevalence of caries (dft>0) in the primary dentition occurred over the last three decades. Among two- to five-year-olds, prevalence increased from 24% in 1988-94 to 28% in 1999-2004, only to decrease again to 23% in 2011-12.[14,15] Dental caries severity (mean df) also increased in the 1990s, but remained unchanged during the 2000s. An average of 2.15 tooth surfaces per child were affected in 1988-94, 2.58 surfaces in 1999-2004, and 2.58 surfaces in 2011-12.[29] In 2011-12, about 9% of children had experienced dental caries in any maxillary anterior primary teeth, one measure of severe caries.

We analyzed publicly available data to determine trends in income-related inequalities in dental caries for children (Figure 1). Absolute inequalities in dental caries experience in the primary dentition increased in the last three decades, particularly in preschool-aged children (Figure 1, panels A and B). In 1988-94, two- to five-year-olds living below the Federal Poverty Level (FPL) had an average of 2.4 more decayed or filled primary tooth surfaces than their more affluent counterparts living at 300% or more of the FPL. By 2011-12, the income gap

had increased to an average of 4.2 tooth surfaces per child. Absolute income-related inequalities in primary dentition caries also increased in six- to 11-year-olds but only slightly, and relative differences remained the same.

During this century, there has been a substantial decrease in the prevalence of untreated caries in the primary dentition. Among three- to five-year-olds, the percentage with untreated dental decay halved: from 23.8% in 1999-2004 to 11.7% in 2011-12.[30] This decrease in prevalence of untreated dental caries
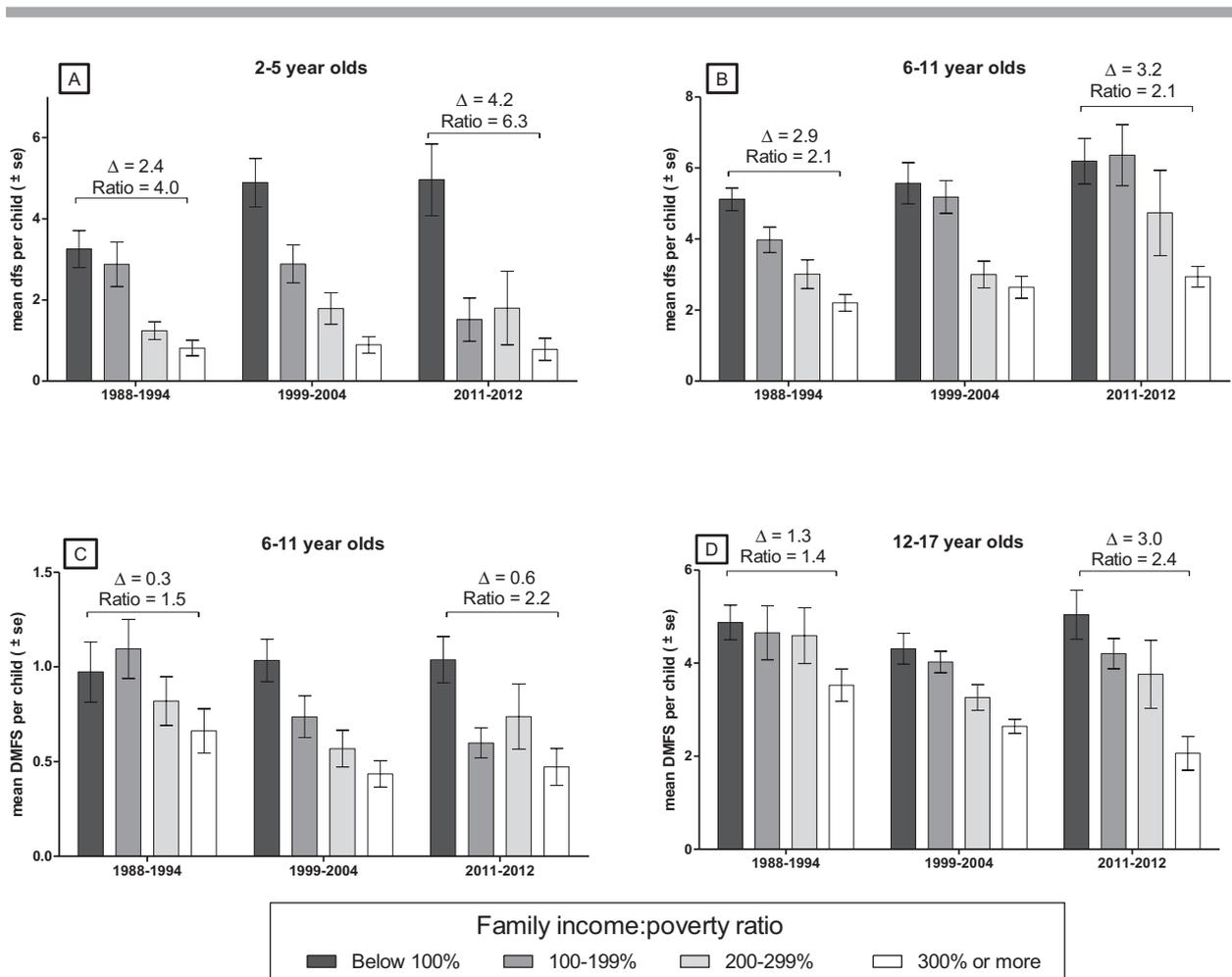

Figure 1. Income inequality in dental caries experience of U.S. children over two decades, by age group

Note: Four categories of income represent approximate quartiles of the distribution of family income divided by poverty level established by the U.S. federal government; dfs=number of decayed or filled primary tooth surfaces per person; DMFS=number of decayed, missing, or filled permanent tooth surfaces per person; se=standard error of estimated mean; Δ=absolute difference in mean caries experience (lowest- minus highest-income category); ratio=relative difference in mean caries experience (lowest- divided by highest-income category).

Sources: Data are from the authors' analysis of National Health and Nutrition Examination Survey datasets for years shown. Datasets were downloaded from www.cdc.gov/nchs/nhanes/nhanes_questionnaires.htm and analyzed using SAS survey estimation procedures to generate population estimates for age groups shown.

in primary teeth was evident across socioeconomic groups, although inequalities continued to be evident. For example, the percentage of children three to five years of age with untreated disease decreased from 34.5% to 17.8% in Mexican Americans, from 27.5% to 20.8% in African Americans, and from 20.1% to 6.1% in whites.

Dental caries in permanent teeth of children and adolescents. After years of framing dental caries in permanent teeth as a universal, unrelenting, and acute condition for children, public health surveys in the late 1970s detected a substantial downward trend in its prevalence and severity.[31-33] The mean DMFS per child aged five to 17 years declined from 7.06 per person in 1971-74 to 4.77 per person in 1979-80, more than two surfaces per child or 32.4%. The mean DMFS per school-aged child declined a further 35.6% by the following national assessment conducted in 1986-87 to an average of 3.07 per child. The decline in dental caries continued through the 1990s but at a slower pace. The mean number of DMFS per child aged six to 11 years decreased from

0.84 surfaces in 1988-94 to 0.68 surfaces in 1999-2004, a decline of 19.0%; and from 5.16 surfaces to 4.33 surfaces per child among 12- to 19-year-olds during that decade, or 16.5%.[14]

In the 21st century, overall changes in caries in permanent teeth appear to be small. A more noticeable trend is that of greater income inequality in caries experience. Absolute differences in mean DMFS for those with the lowest ratio of family income to poverty compared to the highest ratio increased slightly from 0.3 in 1988-94 to 0.6 in 2011-12 (Figure 1, panels C and D). For 12- to 17-year-olds, the difference increased from 1.3 to 3.0 DMFS in the same survey years, indicating larger inequities according to income. The increase for 12- to 17-year-olds was due primarily to improved dental caries severity in the upper income groups.

Dental caries in adults. Changes in caries experience of adults between 1988-94 and 1999-2004 as reported by Dye et al. are summarized in Table 1.[14] Mean DMFT per person declined by an average of 2.21 DMFT in non-elderly adults and 1.16 DMFT in

Table 1. Mean decayed, missing, and filled teeth (DMFT) and decayed and filled teeth (DFT) scores by age, race/ethnicity, and poverty status for U.S. dentate adults, 1988-94 and 1999-2004

	DMFT			DFT		
Variable	1988-94	1999-2004	Difference	1988-94	1999-2004	Difference
Ages 20-64 years						
Race and ethnicity						
White, non-Hispanic	13.04	10.67	-2.37*	9.79	8.49	-1.30*
Black, non-Hispanic	11.61	9.78	-1.83*	5.88	5.67	-0.21
Mexican American	9.03	8.07	-0.96*	6.11	5.66	-0.45
Poverty status						
<100% FPL	11.67	10.22	-1.45*	6.52	6.07	-0.45
100-199% FPL	12.30	10.55	-1.76*	7.26	6.57	-0.69*
≥200% FPL	12.75	10.30	-2.45*	9.74	8.35	-1.38*
Overall	12.54	10.33	-2.21*	8.93	7.81	-1.12*
Ages 65 years and older						
Race and ethnicity						
White, non-Hispanic	19.47	18.23	-1.25*	9.88	9.93	0.04
Black, non-Hispanic	16.74	16.90	0.16	4.20	4.29	0.09
Mexican American	15.69	15.11	-0.59	5.43	5.37	-0.07
Poverty status						
<100% FPL	18.49	17.30	-1.19	5.94	5.10	-0.84
100-199% FPL	18.72	18.21	-0.51	7.03	7.42	0.39
≥200% FPL	19.32	18.15	-1.17*	10.53	10.53	0.00
Overall	19.11	17.96	-1.16*	9.19	9.14	-0.05

FPL=Federal Poverty Level
*Significant at p<0.05

Source: Data were extracted from Table 42 (20-64 years) and Table 63 (65 years and older) in Dye BA, Tan S, Smith V, et al. Trends in oral health status: United States, 1988-94 and 1999-2004. National Center for Health Statistics. Vital Health Stat 2007;11(248).

elderly adults. Among non-elderly adults, the decline was evident in all population subgroups defined by race/ethnicity and poverty status. About one-half of the decline in overall DMFT scores for non-elderly adults was because of a reduction in decayed and filled teeth. None of the decline in DMFT in older adults was due to a change in decayed and filled teeth. In other words, changes in tooth loss had a significant influence on trends in total caries experience (DMFT) in older adults.

Compared to coronal caries in adults, the prevalence of root caries in non-elderly adults was relatively low at 14% in 1999-2004, which represented a decrease from 19% in 1988-94.[14] However, its prevalence was greater for the elderly at 36% (down from 46% in 1988-94) and showed only a small income gradient (44.5% in <100% FPL; 38.3% in ≥500% FPL).

Untreated dental caries in permanent teeth. National trends in the prevalence of untreated dental caries in permanent teeth by age group for the 1990s and 2000s are shown in Figure 2.[14-16] Little change in prevalence occurred in the 1990s among children. However, in the next decade, the percentage of children six to 11 and 12 to 19 years of age with untreated caries in their permanent teeth declined by 27% and 22%, respectively. The percentage of adults 20-64 years of age with any untreated caries changed only slightly over the approximate 20 years between surveys, first trending downward and then upward. The downward trend during the 1990s was much more pronounced in those 65 years of age or
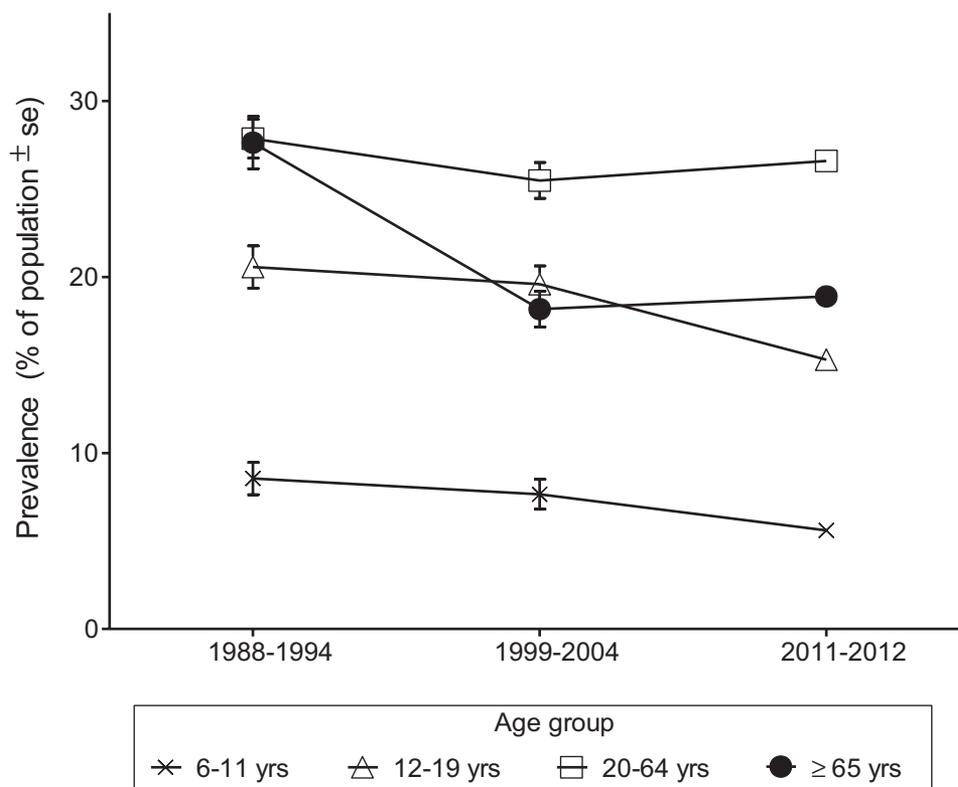

Figure 2. Trends in prevalence of untreated dental caries experience in permanent teeth of U.S. children and adults over two decades

se=standard error of estimated mean, available only for time periods shown with error bars

Sources: Dye BA, Tan S, Smith V, et al. Trends in oral health status: United States, 1988-94 and 1999-2004. National Center for Health Statistics. Vital Health Stat 2007;11(248); Dye BA, Thornton-Evans G, Li X, Iafolla TJ. Dental caries and sealant prevalence in children and adolescents in the United States, 2011-12. NCHS data brief no. 191. Hyattsville, MD: National Center for Health Statistics, 2015; and Dye BA, Thornton-Evans G, Li X, Iafolla TJ. Dental caries and tooth loss in adults in the United States, 2011-12. NCHS data brief no. 197. Hyattsville, MD: National Center for Health Statistics, 2015.

older than for younger adults, but then increased in the following decade.

The prevalence of untreated caries in people of all ages is strongly influenced by social determinants.[34-37] For children, however, differences in income-related untreated caries appear to have narrowed over the last decade, primarily because of improvements in treatment rates among those in lower income families. For example, the percentage of 13- to 15-year-old poor children with any untreated caries in their permanent teeth declined from 27.9% in 1999-2004 to 18.2% in 2011-12.[30] The income disparity in untreated caries prevalence among working-age adults remained about the same between 1999-2004 and 2011-14, but worsened among those 65 years of age or older, reaching an absolute disparity of 32.3 percentage points between the lowest and highest income categories.[34] In 2011-14, the prevalence of untreated caries was 42.2% among adults 65 years of age and older in the ≤100% FPL income category and 9.9% in the ≥400% FPL category.

Projections for dental caries. Based on our review of national surveys of oral health status done over the last four decades, we conclude that 1) the prevalence of dental caries in primary teeth has persisted at similar levels over the years observed; 2) estimates of dental caries prevalence and severity in children and adolescents for whom long-standing trends showed major declines in previous decades have leveled off; 3) only a minority of dental caries goes untreated in children and adults; and 4) an increasing number of adults are retaining more teeth with a small reduction in the average number of teeth per person left in the mouth experiencing dental caries. These largely favorable overall population trends mask large and important disparities in caries experience and its treatment.

We project that overall declines in dental caries experience in permanent teeth of adults will continue to be influenced through 2040 by birth cohorts in the 1970s and onward who benefited from exposures to effective preventive dental services throughout their lives. By 2040, few people will remain in the population who have not benefited from the modern era of preventive dentistry.

The size of the decline in caries experience in adults and its potential significance is uncertain, particularly for the elderly, because of the potential for age effects to dominate over cohort and period effects.[38] But assuming no new national resources are devoted to oral health and no major technologi-

cal advances in caries prevention between now and 2040, we expect that the actual number of DMFT in the non-elderly adult population is unlikely to increase as a result of changes in characteristics of the population. The effects of population dynamics on the burden for caries outcomes are not as clear when missing teeth are excluded from DMFT counts, particularly for the growing elderly population that has experienced little change in caries experience or treatment in recent years.

Periodontal Diseases in Adults

Periodontitis is a chronic inflammatory disease of the supporting tissues around the teeth, which results in irreversible periodontal attachment loss, alveolar bone destruction, subsequent tooth mobility, and, ultimately if left untreated, tooth exfoliation. It is a complex disease resulting from the interplay between bacterial infection and host response. Behavioral factors can modify these relationships. At the individual level, there are multiple causal components, and there is interplay with each other simultaneously.[39] These components include the following: 1) the tooth environment, such as individual variation in subgingival bacteria biofilm on both the tooth root surface and on the pocket epithelial lining; 2) genetics, including individual variation in host defense and epigenetic modifications; 3) systemic diseases, including individual variation in overall health, notably diabetes; 4) lifestyle, including individual variation in oral hygiene, smoking, diet, and stress; and 5) other factors, including possible occlusal/functional problems or iatrogenic causes. In turn, conditions in the places where people live, learn, work, and play affect a wide range of health risks and outcomes. These social determinants of health also play a role in periodontal disease. Individuals with lower income levels or lower education levels are more likely to have periodontal disease.

Prevalence of periodontal diseases. In the most recent data, from the NHANES 2009-12, the prevalence of periodontitis was 46% with about 8.9% having severe periodontitis.[40] Prevalence was greater in males than females. It also was greater in successively older age groups, reflecting cumulative effects of disease on clinical attachment level, which effectively is irreversible and is one of the criteria used to determine prevalence.[41] Periodontitis was more prevalent among Hispanics (63.5%) and non-Hispanic blacks (59.1%) than non-Hispanic whites (40.8%). Fewer years of educational attainment and

lower income were both associated with a greater prevalence of periodontal disease.

Trends in periodontal diseases. Trends in periodontal disease are difficult to evaluate from published reports because they have used different case classifications or have classified the disease using examination protocols that differed in the number of measurements per survey participant. We therefore analyzed data from three cycles of NHANES using the Centers for Disease Control and Prevention-American Academy of Periodontology (CDC-AAP) case definition[42] and measurements made at mesio-buccal sites of teeth in two randomly selected dental quadrants. The CDC-AAP case classification has three ordinal levels: 1) severe periodontitis is 2+ interproximal sites (not on same tooth) with 6+ mm CAL AND 1+ interproximal sites with PPD 5+ mm; 2) moderate periodontitis is either 2+ interproximal sites with 4+ mm CAL (not on same tooth) OR 2+

interproximal sites with 5+ mm PPD (not on same tooth); and 3) no periodontitis, which is neither of the above. Our analysis was limited to people aged 30 years or older because, starting in 2009, periodontitis was measured only in that age range.

We found no consistent trend of either increasing or decreasing prevalence during the two-decade interval. The prevalence of moderate or severe periodontitis was 13.1% (95% CI, 11.7%-14.5%) in 1988-94, 7.6% (95% CI, 6.8%-8.5%) in 1999-2004, and 15.7% (95% CI, 13.8%-17.5%) in 2009-12. In contrast, there was a consistent pattern of pronounced income inequality in periodontitis (Figure 3). In each survey, prevalence in the lowest income quartile was approximately three times the prevalence seen in the highest income quartile.

Assumptions and projections for periodontal disease. Many factors will influence the future burden of periodontal disease. For example, between
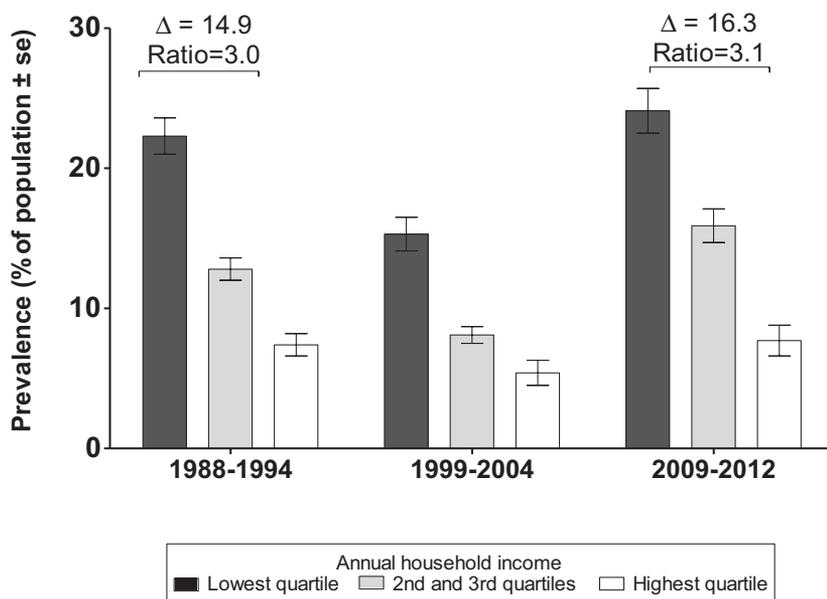

Figure 3. Income inequality in prevalence of moderate or severe periodontitis in U.S. adults aged 30 years or older for three periods

Note: Moderate periodontitis was classified as either 2+ interproximal sites with 4+ mm CAL (not on same tooth) OR 2+ interproximal sites with 5+ mm PPD (not on same tooth). Severe periodontitis was classified as 2+ interproximal sites (not on same tooth) with 6+mm CAL AND 1+ interproximal sites with PPD 5+ mm. To achieve consistency among survey periods, case-classifications were determined using only measurements made at mesio-buccal sites of teeth in two randomly selected dental quadrants. Three categories of income represent approximately the lowest quartile, two middle quartiles, and highest quartile of the distribution of household income; se=standard error of estimated mean; Δ=absolute difference in mean caries experience (lowest- minus highest-income category); ratio=relative difference in mean caries experience (lowest- divided by highest-income category).

Sources: Data are from the authors' analysis of National Health and Nutrition Examination Survey datasets for years shown. Datasets were downloaded from www.cdc.gov/nchs/nhanes/nhanes_questionnaires.htm and analyzed using SAS survey estimation procedures to generate population estimates for age groups shown.

now and 2040, the U.S. population is projected to grow more slowly, continue aging, and become more diverse. The population 18 years and younger will increase by only 6.2%, while the population 65 years and older will increase by 72.2%.[6] The Hispanic population will increase from 13.3% in 2015 to 20.0% in 2040. From NHANES 2009-12 data, we know that the prevalence of periodontal disease increases with age and that racial and ethnic minorities have higher levels of periodontal disease than whites. Based on these data, we might expect the absolute number of people who have periodontal disease would increase by 2040, especially in the 65 years and older age group.

Smoking is a major risk factor for periodontal disease. In 1965, the prevalence of smoking was 42.4%.[43] By 2014, the prevalence had declined to 16.8%. Although projections are not available for smoking prevalence, based on prior history, we would expect smoking rates to decline further between 2015 and 2040, which should reduce the prevalence of periodontal disease.

Diabetes is also associated with periodontal disease. The age-adjusted incidence for diabetes peaked in 2008 at 8.4 per 1,000 population.[44] From 2009 to 2014, the age-adjusted incidence declined from 8.5 to 6.6 per 1,000 population. With respect to prevalence, the number of Americans with diagnosed diabetes is projected to increase, from 11 million in 2000 (prevalence of 4.0%) to 29 million (prevalence of 7.2%) in 2050.[45] Of the projected 18 million increase in the number of cases of diabetes in 2050, 37% are due to changes in demographic composition, 27% due to population growth, and 36% to increasing prevalence rates.

Taken together, these trends in determinants of periodontitis suggest little change in its prevalence, but possible increases in the absolute number of people affected. If fluctuations in prevalence occur, they probably will be smaller than can be detected in population surveys. What does seem clear is that only a small fraction of people experience severe disease and that pronounced income inequalities likely will persist.

Tooth Loss in Adults

The most prominent, proximal causes of tooth loss are dental caries and periodontitis. However, those diseases are not a sufficient explanation for population levels of tooth loss: most adults develop caries or periodontitis during their lifetime, usually in several teeth, while rates of tooth loss are much lower. In the 1970s, an international comparative study of six nations found that levels of complete tooth loss were not strongly associated with levels of dental caries.[46]

Studies examining lifetime risk of tooth loss reveal a richer set of risk factors influencing either tooth loss or its proximal causes that unfold during the life course. They include symptoms of dental disease (e.g., toothache) and fear of dental care.[47] Tooth loss is also influenced by a diverse set of socio-behavioral circumstances,[48] including negative life events, low prestige, depression, needing help from others,[49] psychological stress,[50] and personality attributes such as anxiety.[51] Among behavioral factors, smoking is a recognized predictor for tooth loss,[52] while consumption of carbonated soft drinks[53] and poor oral hygiene[54] are associated with higher rates of dental caries and periodontitis, respectively. Early life influences on risk of tooth loss include parity at birth, birth weight, duration of breast feeding, and pacifier use.[55]

While the amount and quality of dental care are conspicuous factors contributing to the fate of carious or periodontally affected teeth, only a surprisingly modest part of the effect can be accounted for by dentist characteristics. The Florida Dental Care Study found that, after adjusting for dental disease and related symptoms, there was no association between four-year risk of tooth loss and dentist factors such as dentists' beliefs about treatment options, their years since graduation, or their demographic characteristics.[56] Instead, features of the dental practice, such as racial/ethnic distribution of patients seen at the practice, were the strongest practice-level predictors of tooth loss.

By far the most consistent predictor of tooth loss is low socioeconomic status, probably because it signifies a constellation of adverse events that affect many proximate causes of tooth loss cited above. Most studies report strong effects of income and education on levels of tooth loss measured contemporaneously.[46-51] Others, like Thomson et al.,[57] have shown that socioeconomic status at birth, infancy, and childhood is associated with tooth loss in adulthood.

Prevalence of complete tooth loss among adults. Complete tooth loss (edentulism) affected 4.9% of U.S. adults aged ≥15 years in 2009-12, about one-fourth the prevalence seen half a century earlier.[58] Across five national surveys analyzed during that period, prevalence varied most conspicuously according to age group and household income;

gender and race had much weaker associations with prevalence.

Detailed analysis of the half-century time series revealed that most of the difference among age groups reflected historical experiences of different cohorts and not the effects of aging itself.[58] Importantly, when considering future trends, the analysis revealed that cohort effects have all but disappeared for people born since the mid-20th century. Specifically, the two ten-year cohorts born since 1954 had virtually identical age-related rates of increase in edentulism prevalence of around 1% of people per decade. One consequence is that the plunging prevalence of edentulism seen through the end of the 20th century will plateau during the 21st century, due to the passing of people who experienced historically high rates of dental extractions in the first half of the 20th century. Nonetheless, prevalence is projected to decline slowly to reach 2.6% in 2050. The decline will be offset only partially by population growth and population aging, with the projected 8.6 million edentulous adults in 2050 representing a 30% reduction compared to the current 12.2 million edentulous people in 2010.

One aspect of edentulism prevalence that has persisted is its concentration in low-income groups.[58] In fact, in relative terms, the disparity has worsened: during the half-century studied, prevalence declined 98% in relative terms among people living in high-income households, to become virtually eradicated in 2009-12 with a prevalence of 0.6%. Meanwhile, prevalence reduced only 68% in people living in low-income households to reach 12.3% in 2009-12.

Prevalence of partial tooth loss among dentate adults. The same trends and demographic variation in edentulism prevalence are likewise seen in the extent of pathologic tooth loss (i.e., mean number of teeth missing due to caries or periodontal disease) among dentate adults. Findings presented here are from our analysis of four cycles of the NHANES. The mean number of missing teeth plummeted over a four-decade period, with reductions seen in all age groups and among all income categories (Figure 4). Over time, there were reductions in absolute differences between lowest and highest income groups (Δ), whereas there were increases in the relative differences (ratios) between income groups.

By historical standards, the extent and prevalence of tooth loss among people living in high-income households are now remarkably low. For example, in 2009-12, people aged 15-54 years in the highest income quartile had less than one missing tooth per person, on average, and only 8% had one or more missing teeth. In the lowest income quartile, corresponding figures were 1.5 teeth per person and 27% prevalence. For people aged 55 years in the highest income quartile, extent was 2.1 teeth per person, and prevalence was 34%; in the lowest quartile, extent was 7.8 teeth per person, and prevalence was 52%.

In summary, the steep decline in tooth loss during the last half century has left the condition concentrated in low-income groups. Edentulism has been all but cured for people in the upper one-quarter of income distribution. Projected declines in prevalence will be modest, by historical standards. If further inroads are to be made, the gains will need to be made with interventions in middle- and low-income groups.

Discussion

National estimates reveal profound improvements in most indicators of oral health over the last half-century. Caries severity in the permanent dentition of children has plummeted to historically low levels for recorded national surveys, and progress is being made in addressing long-standing inequalities in untreated disease. This downward trend in dental caries prevalence and severity, which started in the 1970s, is carrying over into adulthood as cohorts born since the beginning of the "fluoride era" in the middle of the 20th century continue to be exposed to effective caries preventive methods as they age. Some now characterize dental caries as a slowly progressing, chronic disease affecting people throughout life rather than a rapidly progressing disease of childhood.[59]

Inconsistencies in measurement and case definitions make analysis of trends in periodontal diseases difficult, although one consistent finding is that only a small percentage of the population is affected with severe disease. Tooth loss as a consequence of dental disease has declined unequivocally over the last half century and has all but been eliminated in high-income groups.

Based on our review, we conclude that caries experience will stabilize at present levels in future birth cohorts, but low rates will continue to influence prevalence estimates in adults through 2040. At that time, almost everyone represented in cross-sectional surveys will have been born after the 1970s, when the decline in caries prevalence began. Caries experience
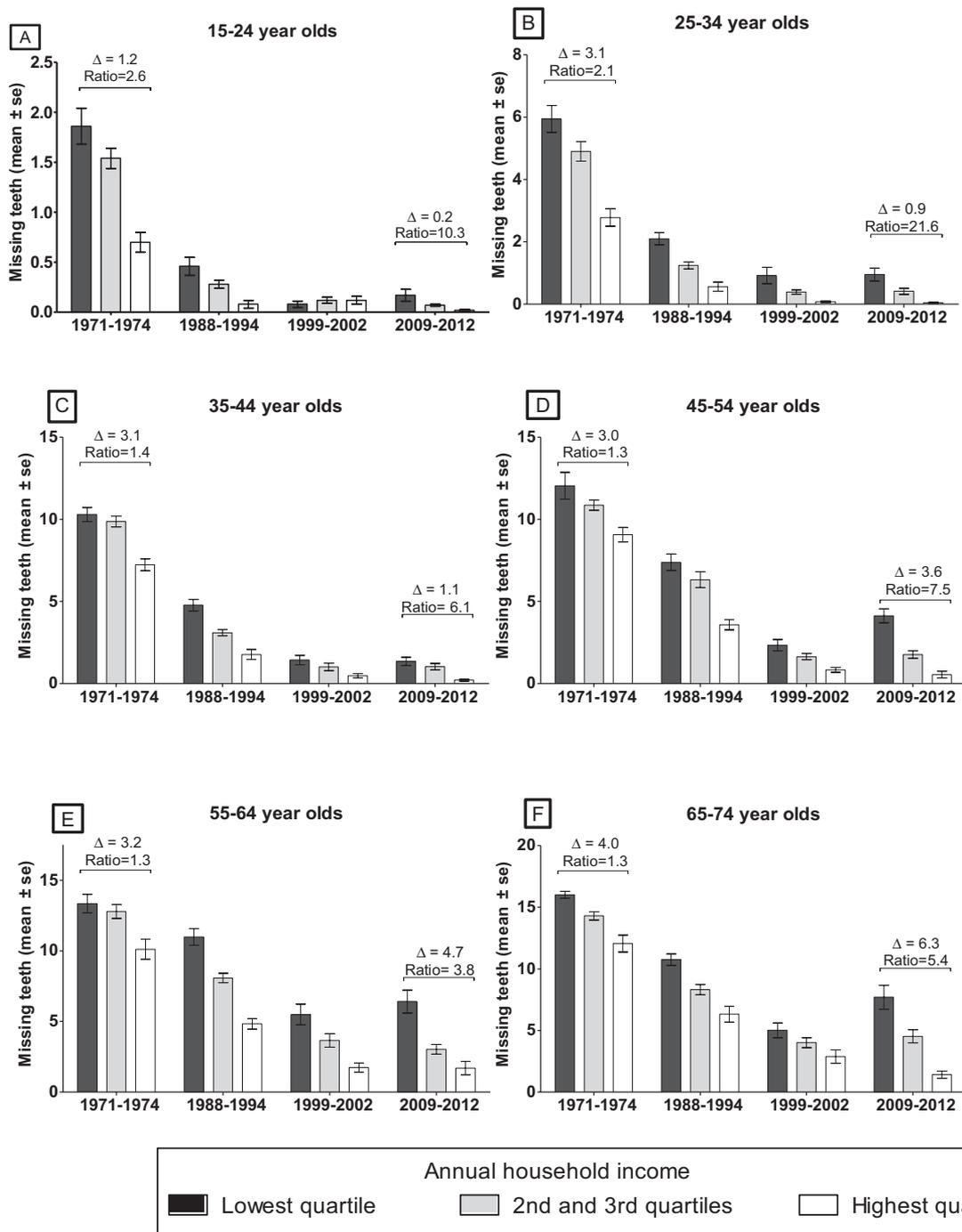
Figure 4. Income inequality in extent of tooth loss among dentate U.S. adults over four decades, by age group

Note: Three categories of income represent approximately the lowest quartile, two middle quartiles, and highest quartile of distribution of household income. Missing teeth are permanent teeth determine by examiners to have been extracted due to dental disease; se=standard error of estimated mean; Δ=absolute difference in mean caries experience (lowest- minus highest-income category); ratio=relative difference in mean caries experience (lowest- divided by highest-income category).

Sources: Data are from the authors' analysis of National Health and Nutrition Examination Survey datasets for years shown. Datasets were downloaded from www.cdc.gov/nchs/nhanes/nhanes_questionnaires.htm and analyzed using SAS survey estimation procedures to generate population estimates for age groups shown.

and tooth loss in adults will continue to decline, but at a slower rate than in recent decades. This view is predicated on the very likely assumption that there will be no major innovations in dentistry or social programs that might affect these oral health outcomes.

More progress has been made in the treatment of dental caries than in its prevention for some ages. This trend is most apparent in the primary teeth of young children for whom caries experience changed very little, but the prevalence of untreated tooth decay halved between 1999-2004 and 2011-12 (from 23.8% to 11.7%).[30] This change in treatment coincided with a shift from a majority of their total caries experience being untreated to a majority being treated.[29] Prevalence of untreated caries in permanent teeth of adolescents 12-19 years of age declined from 19.5% in 1999-2004 to 15.3% in 2011-12.[14,15]

Despite these favorable trends, dental caries can start at a very young age, negatively affects quality of life in its severe forms, and has an unacceptably high prevalence with about two out of every three adolescents being affected. Both the prevalence and severity of dental caries in primary teeth remain high and seem to show few signs of widespread improvement in this country. A considerable investment since the 2000s in clinical care, research, policymaking, and advocacy directed towards dental caries in the primary dentition should yield benefits in the coming years.[60]

Conspicuous inverse social gradients in dental caries, periodontal disease, and tooth loss are evident in all national surveys. It is no coincidence that the United States is undergoing transformations in demographics, the economy, and the educational and literacy skills required to participate productively in society. The oral health status of the nation reflects those transformations. The absolute gap in inequality in oral health between the poorest and wealthiest Americans has persisted or even widened for some of the indicators we examined in this review. At the upper end of the income spectrum, oral health indicators are excellent. Population rates for oral diseases at the lower end of the income spectrum are much worse and are affected primarily by social determinants. It follows that improvements in oral health of the population will require substantial resources and innovative strategies that yield greatest benefits for disadvantaged groups. To be effective, those strategies will require the involvement of many facets of society in addition to dentistry and public health.

Our review presents an incomplete picture of the national burden of disease by focusing on only the three most common conditions affecting the public. Oral conditions like trauma, abnormal dentofacial relationships, temporomandibular joint disorders, oral and pharyngeal cancers, and cleft lip and palate among others are not considered and require resources—often specialized and highly expensive resources. Dentistry also is likely to expand its scope of practice to include medical conditions associated with oral health conditions. Our review did not consider populations that are not represented or are underrepresented in national surveys. The incarcerated, American Indian and Alaska Native populations living on reservations, military populations, and the homeless are among those groups that together represent a large number of people who often have greater oral health needs than the general population and present challenges in providing access to prevention and treatment services.

Conclusion

During the last few decades, most indicators of oral health have improved for most Americans; but powerful influences are driving the nation's population apart and can create further inequities in oral health unless efforts are undertaken to address trends in social determinants along with more proximal causes of clinical disease. Temporal reductions in dental caries prevalence among children appear to have slowed, but prevalence in children should stabilize at low levels and continue to decline in adults. Growing social disparities in oral diseases will be difficult to counteract without innovative, persistent, broad-based, collaborative approaches targeting "upstream" social determinants. Decisions as to whether, and if so how, to address those determinants raise ethical and public health concerns that we believe should be prominent in discussions of dental workforce needs and strategies for the next 25 years.

Disclosure

None of the authors reported any financial interests related to the article.

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