Recent epidemiologic trends in periodontitis in the United States

Abstract

The most important development in the epidemiology of periodontitis in the United States (US) in the last decade is the result of improvements in survey methodologies and statistical modeling of periodontitis in adults. Most of these advancements have occurred as the direct outcome of work by the joint initiative known as the Periodontal Disease Surveillance Project by the Centers for Disease Control and Prevention (CDC) and the American Academy of Periodontology (AAP) that was established in 2006. This report summarizes some of the key findings of this important Initiative and its impact on our knowledge of the epidemiology of periodontitis in US adults.

This Initiative first suggested new periodontitis case definitions for surveillance in 2007 and revised them slightly in 2012. This classification is now regarded as the global standard for periodontitis surveillance and is used worldwide. Application of such standard in reporting finally enables results from different researchers in different countries to be meaningfully compared. Secondly, this Initiative tackled the concern that prior national surveys that used partial-mouth periodontal examination protocols grossly underestimated the prevalence of periodontitis, at potentially more than 50%. Consequently, because previous national surveys significantly underestimated the true prevalence of periodontitis, it is not possible to extrapolate any trend in the periodontitis prevalence in the US over time. Any difference calculated may not represent any actual change in periodontitis prevalence, but rather is a consequence of using different periodontal examination protocols. Finally, the Initiative addressed the gap in the need for state and local data on periodontitis prevalence.

Through the direct efforts of the CDC/AAP Initiative, full-mouth periodontal probing at six sites around all non-third molar teeth were included in the six years of National Health and Nutrition Examination Surveys (NHANES) in 2009 – 2014, yielding complete data for 10,683 dentate community-dwelling US adults ages 30 through 79. Applying the 2012 periodontitis case definitions to the 2009 – 2014 NHANES

This is the author manuscript accepted for publication and has undergone full peer review but has not been through the copyediting, typesetting, pagination and proofreading process, which may lead to differences between this version and the Version of Record. Please cite this article as doi: 10.1111/PRD.12323

data, the periodontitis prevalence turned out to be much greater than previously estimated, namely affecting 42.2% of the population with 7.8% of them having severe periodontitis. It was also discovered that only the moderate type of periodontitis is driving the increase in periodontitis prevalence with age, not the mild or the severe types whose prevalence do not increase consistently with age, but stay around 10% - 15% in all age groups about 40 years old and older. The greatest risk for having periodontitis of any type was seen in older people, in males, in minority race/ethnic groups, in poorer and less educated groups, and especially in cigarette smokers.

The CDC/AAP Initiative reported, for the first time, the periodontitis prevalence estimated at the local and state levels, in addition to the national level. Also, this Initiative developed and validated in field studies a set of eight items for self-reported periodontitis for use in direct survey estimates of periodontitis prevalence in existing state-based surveys. These items were also included in the 2009 - 2014 NHANES for validation against clinically determined cases of periodontitis. Another novel result of this Initiative is that, for the first time, the geographic distribution of practicing periodontists in relation to the geographic distribution of people with severe periodontitis was illustrated.

In summary, the precise periodontitis prevalence and distribution among subgroups in the dentate US non-institutionalized population aged 30 – 79 years is better understood, due to application of valid periodontitis case definitions to full-mouth periodontal examination, in combination with reliable information on demographic and health related measures. We now can monitor the trend of periodontitis prevalence over time as well as guide public health preventive and intervention initiatives for the betterment of the health of the adult US population.

Recent epidemiologic trends in periodontitis in the United States

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Running title: Recent US periodontitis trends

Title of monograph: Periodontics in the USA

Disclaimer: The findings and conclusions in this report are those of the authors and do not necessarily represent the official position of the Centers for Disease Control and Prevention. **Introduction**

Population-based data are fundamental to understanding the distribution and determinants of disease in populations, and their application to prevention programs. The most important trends in the epidemiology of periodontitis in the last decade have centered around improvements in population survey methodologies and statistical modeling of periodontitis for United States (US) adult populations, including the suggestion of a new classification of periodontitis cases for surveillance. Most of these advancements have occurred as the direct results of work by the joint initiative known as the Periodontal Disease Surveillance Project by the Centers for Disease Control and Prevention (CDC) and the American Academy of Periodontology (AAP). Information and findings accruing from these recent advancements have collectively and directly manifested themselves in important results, such as important revisions of our knowledge of the epidemiology of periodontitis in US adults.

Periodontitis is an important public health problem in the US. This is illustrated by the US Department of Health and Human Services designating Oral Health as one of 42 Health Topic Areas identified in Healthy People 2020.[1] Of the 33 objectives within oral health in the future is the goal "OH-5. Reduce the proportion of adults aged 45 to 74 years with moderate or severe periodontitis" set forth by the US Department of Health and Human Services in the 2010 report called Healthy People 2020.[2] Notably, the goal was first set in 2010, but its numeric value for reduction of the prevalence of moderate or severe periodontitis in adults aged 45 to 74 years was later revised and operationalized on the basis of analyses of data from the 2009 – 2010 NHANES collected in accord with the new full mouth periodontal examination protocol. Applying the novel CDC/AAP periodontitis case definitions, the goal is currently a reduction in periodontal diseases from 47.5% to 40.8%.[2]

Assessing the progress towards this goal requires ongoing national disease surveillance and health promotion activities that include monitoring periodontitis prevalence. Federally funded national surveys, such as the National Health and Nutrition Examination Survey (NHANES), have been the only source of nationally representative data on periodontal diseases. Over the years, these surveys have undergone considerable modification to improve the validity of information from the survey, while still keeping the cost of data collection as low as possible. The earliest of these surveys, namely the 1960 – 1962 Health Examination Survey and the 1971 -74 NHANES assessed periodontal status by visual inspection only. In contrast, subsequent surveys, namely the 1985 -1986 National Survey of Employed

Adults and Seniors instituted by the National Institute of Dental and Craniofacial Research (NIDCR), 1988 – 1994 NHANES III, and 1999 – 2004 NHANES, used periodontal probing measurements to assess periodontal probing depth and gingival recession around teeth. These assessments followed various partial-mouth periodontal examination protocols,[3-6] ranging from collecting measurements from two randomly selected quadrants of the mouth assessing periodontal probing depth and clinical attachment loss at two sites per tooth (mesio-buccal and mid-buccal sites) in NHANES III and NHANES 1999 – 2000, to assessing three sites (mesio-buccal, mid-buccal, and disto-buccal sites) in NHANES 2001 – 2004. However, these partial-mouth periodontal examination protocols harbor inherent errors because periodontitis is a site-specific disease and therefore is not evenly distributed in the mouth. Thus, prevalence estimates from surveys using partial-mouth periodontal examination protocols underestimate disease in the population; and this underestimation can be significant in NHANES.[6] Periodontal examinations in NHANES ceased after the 2003 -- 2004 data collection cycle.

Following work by the CDC/AAP Periodontal Disease Surveillance Project, NHANES surveillance of periodontal disease was re-instituted in 2009. The 2009 - 2014 survey protocol was based on evidence from pilot studies that demonstrated the feasibility of using a full mouth periodontal examination protocol for surveillance of periodontitis in NHANES. Thus, beginning with the 2-year NHANES 2009-2010 survey cycle, and later expanded to the NHANES 2011 -12 and NHANES 13 -14 survey cycles, these were the first national probability sample surveys to use the full-mouth periodontal examination protocol, collecting periodontal probing measurements from six sites per tooth for all teeth (except third molars) in US adults. Using this “gold standard” protocol of periodontal measurements from six sites per tooth for all non-third molar teeth to identify periodontitis cases vastly improved the validity of estimates for periodontitis harvested from our national surveys. The NHANES protocols for the 2009 – 2010, 2011 – 2012, and 2013 – 2014 cycles dictated that dentate participants between the ages of 30 and 79 years would be eligible for the periodontal examination. This age interval was determined in order to ensure cost-effectiveness of the resource allocation within NHANES. The lower age limit of 30 years was determined to include only participants most likely to suffer from periodontitis, as people younger than 30 years are less likely to have periodontitis. Only a few participants ages 80 years and older were expected to be dentate, so their inclusion would risk not producing data that would represent this older population group nationally as well as in smaller geographic areas. Consequently, when an expression representing the concept 30 years or older is used in this paper, it refers to the age group 30 years through 79 years of age.

Any figures and results reported by numbers described in the text that are not designated as derived from any previous publication are generated specifically for this paper, based on data from NHANES 2009 – 2014.

Data obtained from these three two-year survey cycles in combination with other co-determined data of socio-demographic, behavioral and co-occurring morbidities provide unprecedented and unique data to re-examine the epidemiologic characteristics of periodontitis in US adult populations and their relationships with several co-morbid conditions. The trust in the accuracy of the data is further supported by the thorough examiner training and calibration of clinical examiners against the gold standard examiner and the subsequent quality assurance emanating from these procedures.[7] Importantly, for the first time in NHANES history, sufficient numbers of non-Hispanic Asians were sampled in the 2011 -- 2012 cycle to provide reliable estimates of their periodontitis prevalence, which further heightens the accuracy of the estimates of periodontitis prevalence.[8]

Development of standard case definitions for surveillance of periodontitis

The historical lack of a standard case definition for surveillance of periodontitis that prevented any meaningful comparisons of findings from different research groups was addressed as a complementary, but pivotal, issue to the survey issue. This void has been a major obstacle in determining, comparing, and pooling estimates for the prevalence of periodontitis from different studies in different populations and countries, as well as between the same populations over time as well as comparison of changes in periodontitis prevalence over time to changes in other populations. In response to the need for a global standard case definition for surveillance of periodontitis, the CDC and AAP initiative undertook extensive studies and consultations with experts to arrive at case definitions for no/mild, moderate, and severe periodontitis for use in surveillance.[9] Further, separate categories for no and mild periodontitis were suggested in 2012.[10]

Applying these stringent periodontitis case definitions ensures that cases identified by the definitions indeed do have disease. In order to minimize the potentially erroneous effect of gingival recession, that may not be a consequence of disease but rather of vigorous tooth brushing, on the accuracy of the probing depth measurements, both clinical attachment loss and periodontal probing depth are used in this classification. Although clinical attachment loss is considered a more accurate measure for periodontitis than periodontal probing depth, and clinical attachment loss is accepted as the gold

standard for disease severity and progression, use of clinical attachment loss alone could mistakenly include some periodontally healthy sites because attachment loss can accompany non-inflammatory gingival recession. In addition, these definitions were based on moderate agreement in the literature that clinical attachment loss of ≥ 6 mm or more is a reasonable cutoff point to differentiate severe from moderate periodontitis, the latter term is usually applied to a clinical attachment loss of 4-5 mm or less. Moderate periodontitis could mean periodontitis in which pocketing and attachment loss are not yet sufficiently severe to threaten the loss of teeth. Hence, this case definition requires at least two sites with periodontal probing depth ≥ 5 mm in addition to CAL, in part to exclude cases that have been treated successfully but still have attachment loss or have attachment loss not resulting from periodontitis. Moreover, measurements from interproximal sites are used in contrast to mid-buccal and mid-lingual sites because the disease usually begins at and is most severe at interproximal sites. Importantly, these case definitions are intended for use in field surveys and not for clinical practice. The CDC/AAP case definitions are operationalized in Table 1:

[Table 1 about here]

Table 1. CDC/AAP periodontitis case definitions for use in surveillance and subsequent categories used in reporting by the CDC/AAP Initiative.

Periodontitis Case Definitions	Criteria[10]	Subsequently Derived Periodontitis Categories	
	Severe *vs* Moderate *vs* Mild *vs* None	**Total* *vs* None**	**Severe *vs* Non-Severe**
Severe	≥ 2 interproximal sites with ≥ 6 mm clinical attachment loss (not on the same tooth) AND ≥ 1 or more interproximal site(s) with ≥ 5 mm periodontal probing depth	Severe	Severe
		Moderate	

Moderate	Among those who did not meet the severe periodontitis case definition: ≥ 2 interproximal sites with ≥ 4 mm clinical attachment loss (not on the same tooth) OR ≥ 2 interproximal sites with periodontal probing depth≥ 5 mm (not on the same tooth)	Mild	Moderate
Mild	Among those who met neither the severe nor moderate periodontitis case definitions: ≥2 interproximal sites with ≥3 mm clinical attachment loss AND (≥2 interproximal sites with ≥4 mm periodontal probing depth (not on the same tooth) OR 1 site with ≥5 mm periodontal probing depth)		Mild
None	Meets neither the severe nor moderate nor mild periodontitis case definitions	None	None

*Total periodontitis was defined as severe or moderate periodontitis in the 2010 report on accuracy of estimates based on earlier NHANES protocols,[6] because the CDC/AAP periodontitis case definitions consisted of only the categories severe, moderate, and mild/none at the time.[9] The mild category was separated out from the original mild/none periodontitis category in 2012.[10]

Total periodontitis*(= "any" periodontitis): severe or moderate or mild periodontitis.[8, 11-17]

Non-severe periodontitis (= "other" periodontitis): moderate or mild periodontitis.[17]

Several studies have validated these case definitions relative to clinical observations and report strong correlations between the periodontal inflamed surface area and case status based on this classification.[18]

Gingivitis

Gingivitis is nearly ubiquitous with up to 90% in any population worldwide affected.[19] The 2017 World Workshop proposed case definitions for gingival health and for gingivitis for use in surveillance.[20]

Nonetheless, because no assessments of gingival health, such as bleeding on probing, coloring, or swelling, was not included in the protocol for 2009 - 2014 NHANES to examine for gingivitis, no further description will be provided regarding the prevalence of this reversible disease that only progresses to periodontitis in especially susceptible individuals.[21, 22]

Application of the CDC/AAP periodontitis case definitions as global standards

The CDC/AAP case definitions are gradually being adopted globally as the standard for reporting the prevalence of periodontitis and have been used in a multitude of studies around the world. Of great importance is that the CDC/AAP periodontitis case definitions are among those that should be applied when reporting the prevalence of periodontitis, as per a consensus report by experts in Europe and the US outlining standard reporting of periodontitis prevalence in the future in their document named "Proposed standards from the Joint EU/USA Periodontal Epidemiology Working Group."[23]

Revised estimates of periodontitis prevalence in US adults

Applying the CDC/AAP case definition for periodontitis to the pooled data from all the six years that NHANES followed the protocol prescribing periodontal probing at six sites around all non-third molar teeth, namely the years 2009 – 2014, resulted in significant revisions of the estimates of prevalence of periodontitis in US adults. Complete clinical periodontal examinations, sociodemographic, health behavior, and co-morbidity data were available for 10,683 participants constituting a nationally representative sample representing a weighted population of approximately 143.8 million civilian noninstitutionalized dentate US adults 30 years or older.

This ensures that analyses of these data will result in the most accurate estimates of the prevalence of periodontitis and its associated risk factors currently in existence in the world. Hence, findings from our analyses of these data function as a benchmark for surveys conducted in the rest of the world. Our reporting the prevalence of periodontitis using both the CDC/AAP case definitions as well as various thresholds of periodontal probing depth and clinical attachment loss and units of population, teeth, and sites further enhances the utility of the results, in addition to making the data publicly available.

Total (any) periodontitis: Notably, the prevalence of periodontitis in dentate US adults aged 30 -- 79 years was significantly higher than previously reported. Overall, 42.2 % (standard error [SE] $\pm$1.4) of US dentate adults $\geq$30 years had some category of periodontitis, consisting of 7.8% with severe periodontitis and 34.4% with non-severe periodontitis (i.e., moderate and mild periodontitis combined)(Fig. 1).

[Fig. 1 about here]

Furthermore, the prevalence of periodontitis by these severity groups and by age group (Fig. 2) and smoking status (Fig. 3), respectively, is shown in Figures 2 and 3.

[Fig. 2 about here]

[Fig. 3 about here]

The prevalence of periodontitis among the oldest age group, 65 – 79 years, is described in more detail in a separate report based on analyses on data from the 2009 - 2010 and 2011 - 2012 NHANES cycles.[16]

Periodontal probing depth: At the probing site level, the mean periodontal probing depth was 1.5 mm. About 37.5% had >1 site with periodontal probing depth >4 mm, affecting on average 3.3 % of sites and 9.1% of teeth per person.[17] Overall, the mean proportion of sites with periodontal probing depth > 4 mm was 3.3 %. At the tooth level, 29.3% had periodontal probing depth > 4mm at > 5% of their teeth, whereas 10.5% had > 30% of their teeth affected by periodontal probing depth > 4mm. The overall mean proportion of teeth with PDD > 4 mm was just under 1-in-10 (9.1%). However, almost half of the older adults (i.e., ≥ 65 years of age) had at least one site with periodontal probing depth ≥ 4 mm. An estimated 15.0% of adults had periodontal probing depth > 4 mm at > 5% of all sites and 2.7% at >30% of all sites.[17]

Clinical attachment loss: The population mean clinical attachment loss was 1.7 mm.[17] About 89% had >1 site with clinical attachment loss >3mm with an average of 19.0% of sites per person and an average of 37.1% of teeth per person affected.

Overall, an estimated 58.3% had >3 mm clinical attachment loss in >5% of sites; and the mean proportion of sites with >3 mm clinical attachment loss was 19.0%. At the tooth-level, 80.8% of adults had clinical attachment loss > 3 mm at > 5% of their teeth, while 47.3% had >30% of their teeth affected by clinical attachment loss > 3mm. The mean proportion of teeth with > 3 mm clinical attachment loss was 37.1%. Among older adults (i.e., ≥ 65 years of age), almost two-thirds (62.3%) had at least one site with ≥ 5 mm CAL.[17]

Trends in periodontitis prevalence in US adults

Because the former nationally representative surveys all used partial-mouth periodontal examination and thereby possibly missed a significant proportion of the disease, possibly misclassifying more than half the participants,[6] any difference in prevalence calculated is more likely to be a consequence of applying different examination protocols than to reflect any actual change in the prevalence of periodontitis. Hence, it is not possible to know whether the periodontitis prevalence is increasing or

decreasing in the US. However, we can speculate that because people live longer and keep their teeth longer into older age and because periodontitis per definition is a chronic disease that accumulates in an individual over the adult lifetime, it is reasonable to anticipate increasing numbers of people and teeth with periodontitis.

Risk indicators for periodontitis

Similarly, using data from the 2009 – 20014 NHANES, we reassessed risk indicators for periodontitis after controlling for socio-demographic, behavioral, and co-morbid conditions, using multivariable logistic regression modeling. Figure 4 illustrates the risk ratios for having severe periodontitis.

[Fig. 4 about here]

Consistent with what was hitherto known, the likelihood of having total (any) or non-severe periodontitis increased steadily with increasing age. However, this was not the case for the prevalence of severe periodontitis, which did not increase with age (Fig. 4). As an aside, since the prevalence of mild periodontitis also did not consistently increase by age (not shown),[17] the increase in periodontitis prevalence by age is primarily driven by the moderate class that also comprises the largest severity group, that is, the overall prevalence of moderate periodontitis is much greater than that of severe and mild, respectively.[17] The likelihood of having periodontitis was two times greater among males compared to females with the highest probability observed for severe periodontitis (aPR=2.68; 2.22 – 3.23) (Fig. 4). Periodontitis was most likely present among Hispanics (aPR=1.38; 1.26-1.52) and non-Hispanic blacks (aPR=1.35; 1.22-1.50); and severe periodontitis was most likely among non-Hispanic blacks (aPR=1.82; 1.44-2.31) compared to non-Hispanic whites (Fig. 4). Adults who have less than a high school education were more likely to have periodontitis, with the greatest probability observed for severe periodontitis (aPR = 1.63, 1.26 – 2.12) (Fig. 4), but also sizeable for non-severe periodontitis (aPR = 1.29, 1.15 – 1.45) compared to those with more than a high school education. The highest probability for severe periodontitis was seen among adults with income levels at the 100 – 199% of the federal poverty level (aPR = 1.82, 1.22 – 2.71) (Fig. 4), while the highest probability for non-severe periodontitis was seen among the poorest at less than 100% federal poverty level (aPR = 1.44, 1.26 – 1.56). Overall, there was a steady increase in the likelihood of periodontitis with increasing poverty (decreasing federal poverty level) (not shown). Periodontitis was significantly more likely among current and former smokers compared to non-smokers. The likelihood for periodontitis was highest among current smokers (aPR = 1.54, 1.45 – 1.65), and smoking was strongly associated with the severe form of periodontitis (aPR = 2.46, 1.87 – 3.24) (Fig. 4). Among persons with diabetes, periodontitis was more likely only in those with uncontrolled diabetes, specifically pertaining to severe periodontitis (aPR = 1.42, 1.02 – 1.98)

(Fig. 4). Periodontitis was not significantly associated with obesity status. Of note, severe periodontitis was neither associated with overweight nor obesity (Fig. 4). Finally, the likelihood of severe periodontitis was greatest in adults younger than 65 years, in males, in non-Hispanic blacks, and in current cigarette smokers when compared to non-severe periodontitis.

When stratified by sex, severe periodontitis was more likely among females aged 65 years and older. Periodontitis was equally likely in female former smokers and non-smokers. In females, periodontitis and non-severe periodontitis were not significantly associated with diabetes status. In contrast, all levels of severity of periodontitis were more likely among males with uncontrolled diabetes when compared with males without diabetes. Finally, when compared to persons with non-severe periodontitis, the likelihood of severe periodontitis was significantly greater in males of all age groups and education status, and for Non-Hispanic blacks and current smokers, regardless of sex.

Further analyses of periodontitis and diabetes also suggest that the duration of diabetes did not significantly correlate with the likelihood of periodontitis after adjusting for all covariates (Wald F test, $p>0.05$). Similarly, no trend was observed between periodontitis and fasting glucose level amongst persons with diabetes (Wald F test, $p>0.05$). In females without diabetes, total periodontitis and non-severe periodontitis (but not severe periodontitis) significantly increased with increasing levels of fasting glucose levels ($p<0.05$). In males without diabetes, no trend was observed for any level of severity of periodontitis and increasing fasting glucose levels ($p>0.05$). Periodontitis was significantly associated with increasing levels of glycated hemoglobin in both males and females without diabetes ($p<0.05$). Among persons with diabetes, only severe periodontitis was significantly correlated with increasing levels of glycated hemoglobin in males.

Estimating periodontitis at state and local levels

Until recently, population estimates of periodontitis were virtually non-existent at the state and local levels, even though most public health interventions are administrated at state and local populations. This is attributable to the lack of resources within existing state-based oral health surveillance systems to support clinically assessed periodontal measurements. Thus, for now, population-based surveillance at the state and local levels will require developing less resource-demanding measures that can be integrated into existing surveillance systems. Alternatively, multi-level statistical modeling can generate

estimates of the burden of periodontitis at the state and local levels.

Direct estimation of periodontitis at the state and local levels

Currently, there are several ongoing interview-based surveys at the national, state, and local levels that can be explored for surveillance of periodontitis. In the US, measures derived from responses to self-report questions incorporated into state interview surveys (e.g., the state based Behavioral Risk Factor Surveillance System) have been successful in generating actionable public health data for several chronic diseases and risk factors at the state and local levels.[24, 25] Thus, since 2006, the CDC/AAP Periodontal Disease Surveillance Initiative has been investigating the potential use of self-report measures for estimating prevalence of periodontitis in adult populations. Among ways to identify appropriate, relevant, and validated questionnaire items for potential use for self-report was the conduction of a systematic review of studies that sought to validate self-reported measures for periodontal disease.[26] Another avenue was to examine items used in prior work by members of the CDC/AAP Initiative's workgroup who had conducted epidemiologic studies encompassing both self-reported and clinically assessed periodontitis, hence allowing assessment of the validity of the items as proxies for actual clinically assessed periodontal disease.[27-29]

The CDC/AAP initiative identified eight self-report measures that are promising for use in estimating prevalence of periodontitis in adult populations as their responses are correlated with the clinical measures of periodontitis.[11] The questions in English languish are displayed in Table 2, whereas the Spanish version may be found in the 2009 report.[11]

Table 2. Questions for self-report of periodontitis identified as promising for potential use in survey-based surveillance in lieu of resource intensive clinical periodontal examinations.[11]

Item #	Item verbatim	Response options
1.	Do you think you might have gum disease?	yes/no/refused/don't know
2.	Overall, how would you rate the health of your teeth and gums?	excellent/very good/good/ fair/poor/refused/don't know
3.	Have you ever had treatment for gum disease such as scaling and root planing, sometimes called "deep cleaning"?	(yes/no/refused/don't know

4.	Have you ever had any teeth become loose on their own, without an injury?	yes/no/refused/don't know
5.	Have you ever been told by a dental professional that you lost bone around your teeth?	yes/no/refused/don't know
6.	During the past three months, have you noticed a tooth that doesn't look right?	yes/no/refused/don't know
7.	Aside from brushing your teeth with a toothbrush, in the last seven days, how many times did you use mouthwash or other dental rinse product that you use to treat dental disease or dental problems?	number of days:_____ /refused
8.	Aside from brushing your teeth with a toothbrush, in the last seven days, how many times did you use dental floss or any other device to clean between your teeth?	number of days:_____ /refused

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Using multivariable prediction models, the performance of these self-report measures was evaluated in the Australian National Adult Oral Health Surveys[30] and in a convenience sample of adults in Brazil.[31] Importantly, the items were cognitively tested, and pilot field tested in one NHANES stand before being incorporated in the full NHANES.[11]

In these preliminary assessments, the response rates to all self-report questions in-home interviews were high, namely at > 95%. All self-reported measures were independently associated with periodontitis, except for the use of mouthwash. Self-reported questions had no significant correlations with one another, with the exception of the use of mouthwash and evidence of bone loss.[11] In multivariable modeling, the combined effects of demographic measures and measures from five self-report questions in detecting unweighted total periodontitis performed at a sensitivity of 84%, specificity of 60%, and receiver operating characteristic of 0.81. Three questions performed at a sensitivity of 95%, specificity of 28%, and receiver operating characteristic of 0.82 in predicting clinical attachment loss of $\geq$ 3mm. In validation tests, the two models performed at prediction accuracies of 70% and 89%, respectively.

These results confirm that self-report measures can perform well in predicting prevalence for periodontitis in the US adult population. Notably, our preliminary findings suggest the performance of these questions may exceed the accuracy of estimates from partial mouth examination protocols commonly used in surveillance of periodontitis, especially for severe periodontitis.[6]

In 2009, the CDC initiative began inclusion of these self-report questions in the home interview questionnaire for the NHANES. The data from the 2009 – 2014 cycles will be used to test and validate the performance of these self-report questions against clinically determined periodontitis. The full mouth examination protocol used in NHANES provides clinical data that will minimize misclassification of periodontitis cases for this validation study. Analyses of the data is in progress to generate the model coefficients for use in estimating periodontitis in populations based on responses to self-report questions. The self-report questions are still incorporated in NHANES and will be used in the future for monitoring the prevalence of periodontitis and assess the trends over time. This will for the first time allow such trends to be calculated with the assurance of the agreement with the clinically assessed periodontitis during the six years 2009 – 2014 once they are validated.

Model estimation of periodontitis prevalence at the state and local levels

With the availability of comprehensive NHANES data and the concurrent availability of local and state datasets, such as those from the US Census and the Behavioral Risk Factor Surveillance system, it is now possible to estimate periodontitis prevalence at the state and local levels. In a recent study, multilevel regression and post-stratification analyses were used to estimate the prevalence of periodontitis among adults aged 30-79 years at state, county, congressional district, and census tract levels.[15] This modeling approach used age, race, sex, smoking, and poverty variables to estimate the prevalence of periodontitis as defined by the CDC/AAP case definitions at the census tract levels, which subsequently were aggregated to larger administrative and geographic areas of interest. This report was the first time any estimation of the prevalence of periodontitis at state and local levels based on nationally representative data was performed in the US and represents an important adjunct to public health surveillance efforts to identify areas with high burden of periodontitis.[15]

Based on the NHANES 2009 – 2012 data, the model-estimated mean prevalence of periodontitis among the states was 45.1% (median 44.9%) and ranged from 37.7% in Utah, to 52.8% in New Mexico, representing an estimated 15 percentage points disparity in prevalence among states. County estimates

ranged from 33.7% to 68.0% (mean 46.6%, median 45.9%), representing a much larger disparity of 34 percentage points in periodontitis prevalence among counties, a two-fold difference (not shown).[15] The mean prevalence of severe periodontitis among the states was 8.9% (median 8.8%) and ranged from 6.4% in Utah to 11.3% in New Mexico. Among the counties, the mean prevalence was 9.2% and the median 8.8%, ranging from 5.2% to 17.9%. In other words, in the county with the greatest prevalence of severe periodontitis this prevalence is more than three times greater than the prevalence in the county with the lowest prevalence (not shown).[15]

Table 3. Model-based estimates of total and severe periodontitis prevalence by state or district – NHANES 2009 – 2012.[15]

State or District	Total, % (95% CI)	Severe, % (95% CI)
Alabama	47.39 (47.26, 47.52)	9.80 (9.75, 9.85)
Alaska	43.60 (43.32, 43.89)	8.72 (8.60, 8.83)
Arizona	47.73 (47.62, 47.84)	9.46 (9.41, 9.50)
Arkansas	47.23 (47.05, 47.41)	9.57 (9.50, 9.63)
California	47.80 (47.75, 47.84)	9.42 (9.40, 9.43)
Colorado	43.29 (43.17, 43.40)	8.26 (8.22, 8.30)
Connecticut	43.35 (43.22, 43.47)	8.18 (8.14, 8.23)
Delaware	45.86 (45.60, 46.11)	9.03 (8.93, 9.14)
District of Columbia	50.08 (49.79, 50.37)	11.18 (11.04, 11.33)
Florida	49.47 (49.41, 49.55)	10.00 (9.97, 10.03)
Georgia	46.41 (46.31, 46.51)	9.51 (9.47, 9.54)
Hawaii	51.10 (50.88, 51.32)	10.56 (10.45, 10.66)
Idaho	42.72 (42.44, 43.01)	7.87 (7.77, 7.97)
Illinois	44.87 (44.80, 44.94)	8.79 (8.76, 8.81)
Indiana	44.18 (44.07, 44.30)	8.58 (8.54, 8.63)
Iowa	42.10 (41.95, 42.25)	7.66 (7.61, 7.71)
Kansas	43.28 (43.13, 43.42)	8.17 (8.11, 8.22)
Kentucky	45.17 (45.03, 45.32)	8.89 (8.84, 8.94)
Louisiana	48.21 (48.08, 48.33)	10.26 (10.2, 10.31)
Maine	42.90 (42.63, 43.16)	7.90 (7.80, 7.99)
Maryland	45.25 (45.15, 45.35)	8.97 (8.93, 9.01)
Massachusetts	42.80 (42.70, 42.89)	8.01 (7.98, 8.05)
Michigan	45.13 (45.05, 45.21)	8.95 (8.91, 8.98)
Minnesota	41.66 (41.55, 41.77)	7.68 (7.64, 7.72)
Mississippi	49.22 (49.04, 49.42)	10.58 (10.5, 10.65)
Missouri	45.12 (45.00, 45.24)	8.88 (8.83, 8.93)
Montana	44.29 (43.98, 44.57)	8.41 (8.30, 8.52)
Nebraska	42.85 (42.65, 43.02)	8.00 (7.93, 8.07)
Nevada	47.84 (47.69, 47.98)	9.68 (9.63, 9.74)
New Hampshire	40.51 (40.28, 40.73)	7.27 (7.18, 7.36)
New Jersey	45.26 (45.18, 45.33)	8.82 (8.79, 8.86)
New Mexico	52.79 (52.60, 52.97)	11.32 (11.23, 11.41)
New York	46.59 (46.54, 46.65)	9.28 (9.26, 9.30)
North Carolina	46.53 (46.44, 46.62)	9.47 (9.43, 9.50)
North Dakota	42.42 (42.11, 42.76)	7.85 (7.73, 7.98)
Ohio	44.45 (44.37, 44.54)	8.70 (8.66, 8.73)
Oklahoma	46.98 (46.85, 47.12)	9.49 (9.44, 9.54)
Oregon	43.63 (43.48, 43.78)	8.12 (8.07, 8.18)
Pennsylvania	44.41 (44.34, 44.49)	8.56 (8.54, 8.59)
Rhode Island	43.63 (43.38, 43.88)	8.26 (8.17, 8.35)
South Carolina	47.78 (47.67, 47.90)	9.91 (9.86, 9.96)
South Dakota	43.55 (43.26, 43.87)	8.25 (8.15, 8.37)
Tennessee	46.18 (46.07, 46.30)	9.30 (9.25, 9.35)
Texas	48.25 (48.19, 48.31)	9.86 (9.84, 9.89)
Utah	37.69 (37.51, 37.86)	6.36 (6.31, 6.41)
Vermont	41.43 (41.09, 41.77)	7.47 (7.35, 7.59)
Virginia	44.29 (44.21, 44.36)	8.65 (8.62, 8.69)
Washington	42.92 (42.81, 43.02)	8.01 (7.98, 8.05)
West Virginia	45.69 (45.46, 45.92)	8.88 (8.79, 8.97)
Wisconsin	42.71 (42.59, 42.83)	8.02 (7.98, 8.06)
Wyoming	42.85 (42.51, 43.24)	8.01 (7.89, 8.15)

The geographic distribution of estimated periodontitis prevalence at the state, county, congressional district, and census track levels is presented in Figure 5.[15]

[Fig. 5 about here.]

Overall, the greatest burden of periodontitis was observed among southeastern and southwestern states, concentrated in pockets stretching along the Southeast, in the Mississippi Delta, along the US-Mexican border, and among Native American reservations. Other areas severely affected by

periodontitis were southern Florida, Hawaii, and remote areas of Western Alaska. Overall, similar geographic patterns were determined for severe periodontitis. The prevalence of severe periodontitis in each state is shown in Figure 6.

[Fig. 6 about here.]

Among older adults (≥ 65 years old) by states, we estimated the lowest prevalence of periodontitis in Utah (62.3%) and New Hampshire (62.6%) and the highest in New Mexico, Hawaii, and the District of Columbia (DC), each with a prevalence greater than 70%. Overall, periodontitis is highly prevalent in this older sub-population with towards a minimum of two-thirds of dentate older adults affected at any geographic level.

Distributions of severe periodontitis and periodontists in the US

Multivariable geospatial analysis was used to examine the distribution of periodontists and adults, periodontists vis-à-vis estimated density of adults with severe periodontitis, and their ratios to adults with severe periodontitis,[32] taking advantage of the locations identified through the National Provider Identifier (NPI) Registry.[33] Overall, about 60% of adults > 30 years live within 5 miles of a periodontist, 73% within 10 miles, 84% within 20 miles, and 97% within 50 miles. Proximity to a periodontist varied widely. In urban areas, 95% of adults resided within 10 miles of a periodontist and 99% within 20 miles. Only 25% of adults in rural areas lived within 10 miles of a periodontist. Most periodontists (96.1%) practiced in urban areas, clustering along the eastern and western coasts and in the Midwest; 3.1% in urban clusters elsewhere, and 0.8% in rural areas. Ratios of < 8,000 adults with periodontitis to > 1 periodontist within 10 miles were mostly clustered in the Northeast, central east coast, Florida, west coast, Arizona, and Midwest.

Conclusion

Overall, significant progress has been made in laying the groundwork for future data for epidemiologic studies of periodontitis. Importantly, a much-improved surveillance framework and data standards have been established that has resulted in the revision of the burden of periodontitis in US adults. Replication of these standard surveillance protocols over time will allow reporting of trends in periodontitis prevalence over time. Efforts to determine true trends in periodontitis have been hampered by the different and inconsistent, partial mouth periodontal recording survey protocols used in the past. The greatly improved data have allowed us to better identify risk indicators and determinants of periodontitis. For example, we were able to demonstrate that the relationship between periodontitis

and diabetes is limited to only severe periodontitis and un-controlled diabetes, while periodontitis was not associated with obesity.

There is much improvement in the prospects for direct surveys or modeling estimation of periodontitis at the state and local levels, which will open up epidemiological studies for public health intervention of periodontitis at the local levels. Since periodontitis is a public health problem in itself due to its effect on quality of life, but also is associated with other common systemic diseases and conditions, it is of great importance that future prevention and intervention programs and activities now can be based on nationally representative data. Finally, it is possible to monitor the prevalence of periodontitis to assess the progress in reaching the goal of reducing the prevalence of moderate and severe periodontitis in the adult US population proposed by the Healthy People 2020 initiative.

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Acknowledgements

The authors would also like to acknowledge the members of this CDC/AAP Workgroup.[12] No funding was received for writing this paper.

Figures

Figure 1

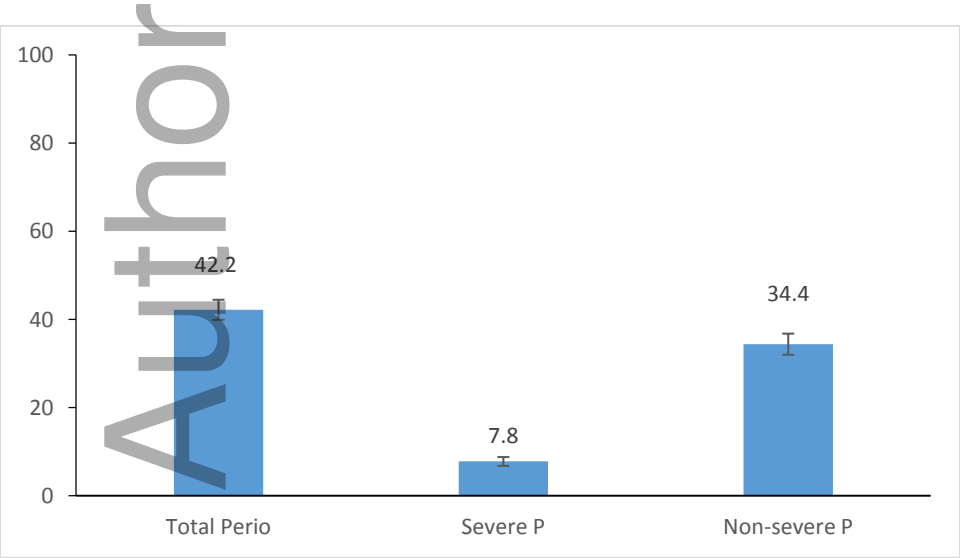

Figure 2

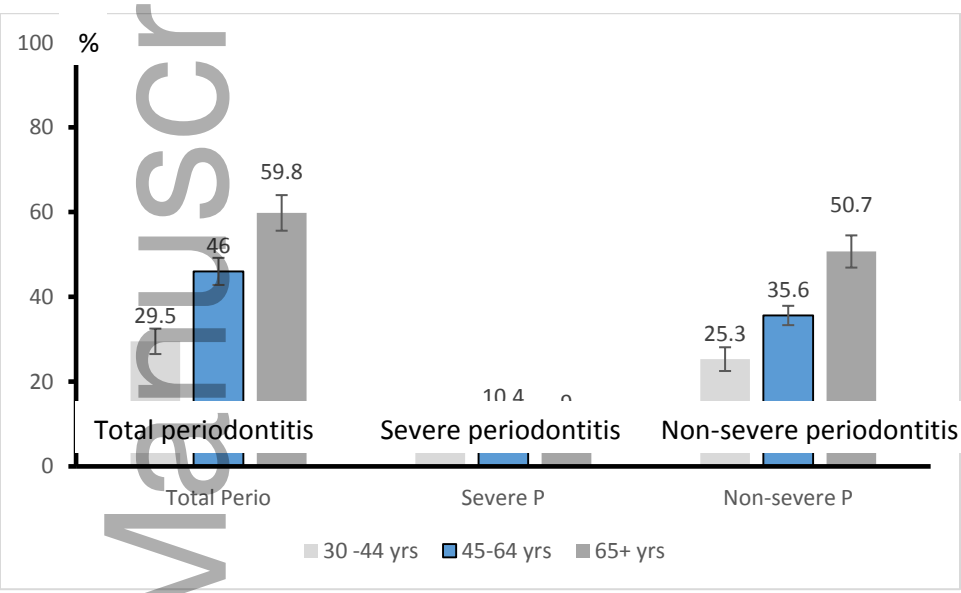

Figure 3

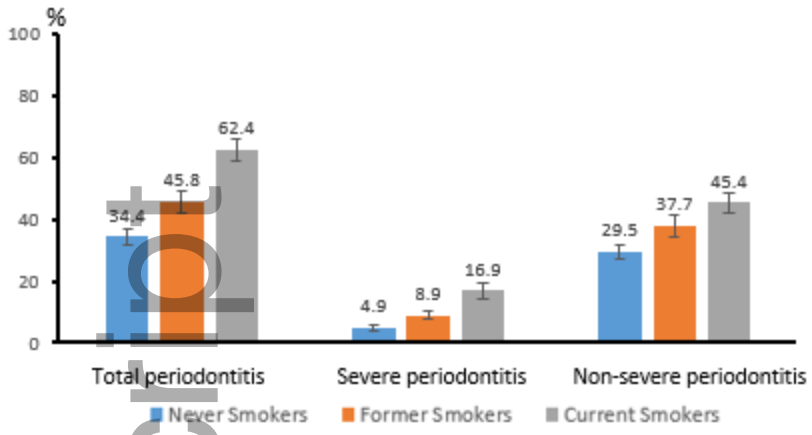

Figure 4

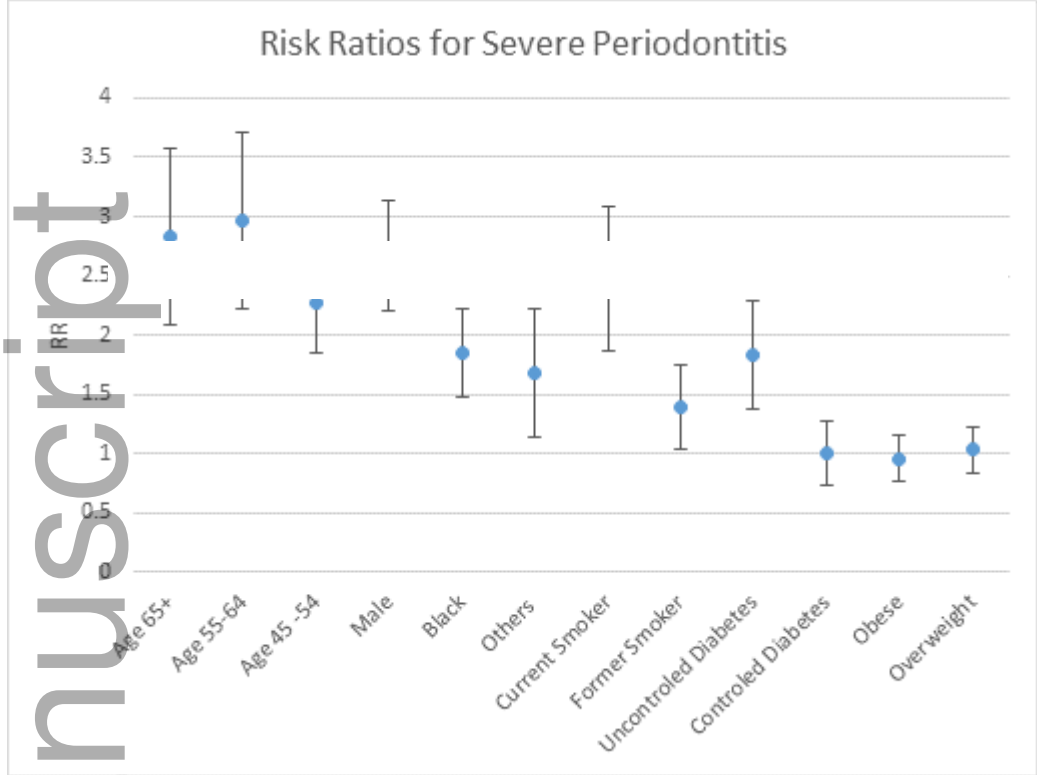

Figure 5

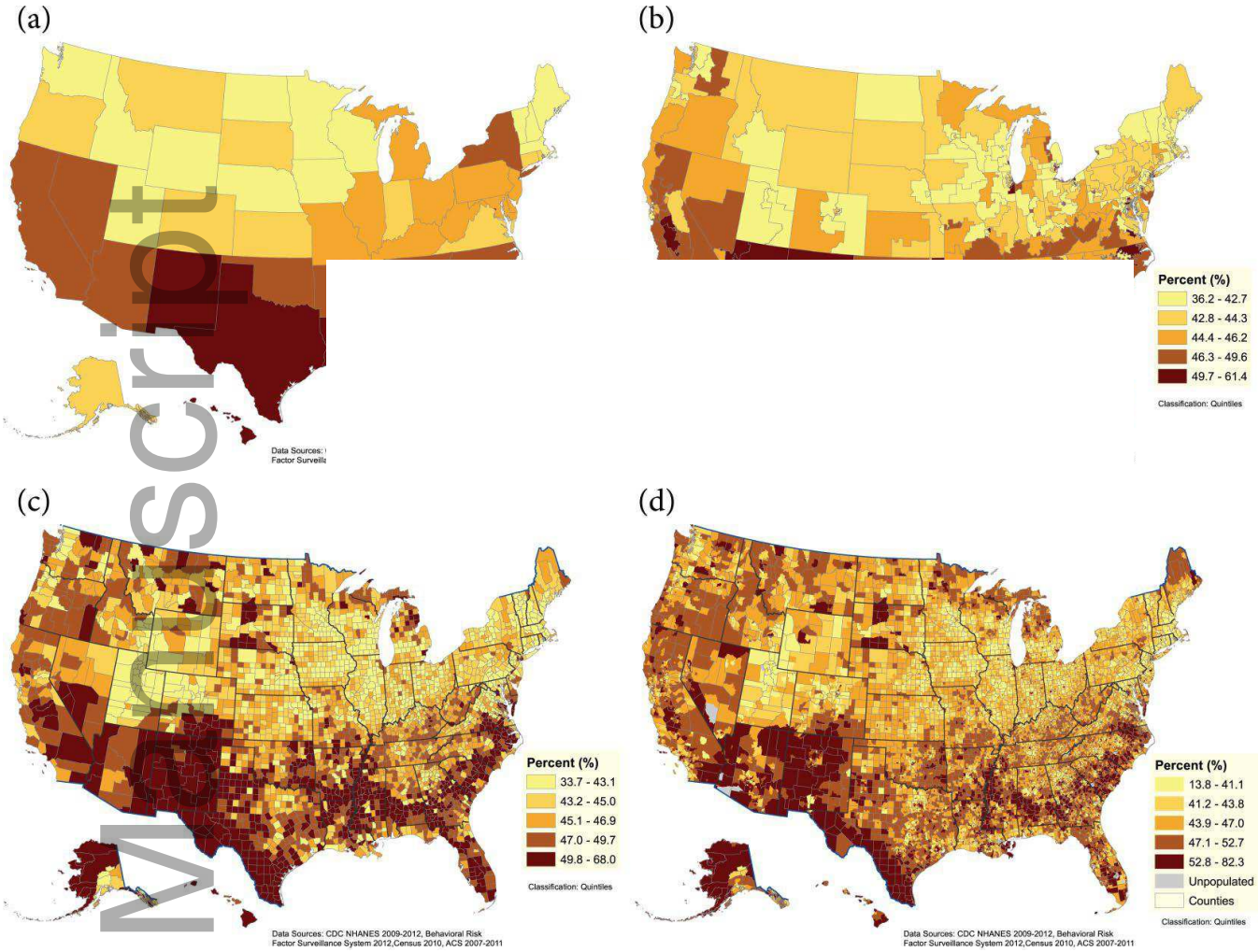

Figure 6

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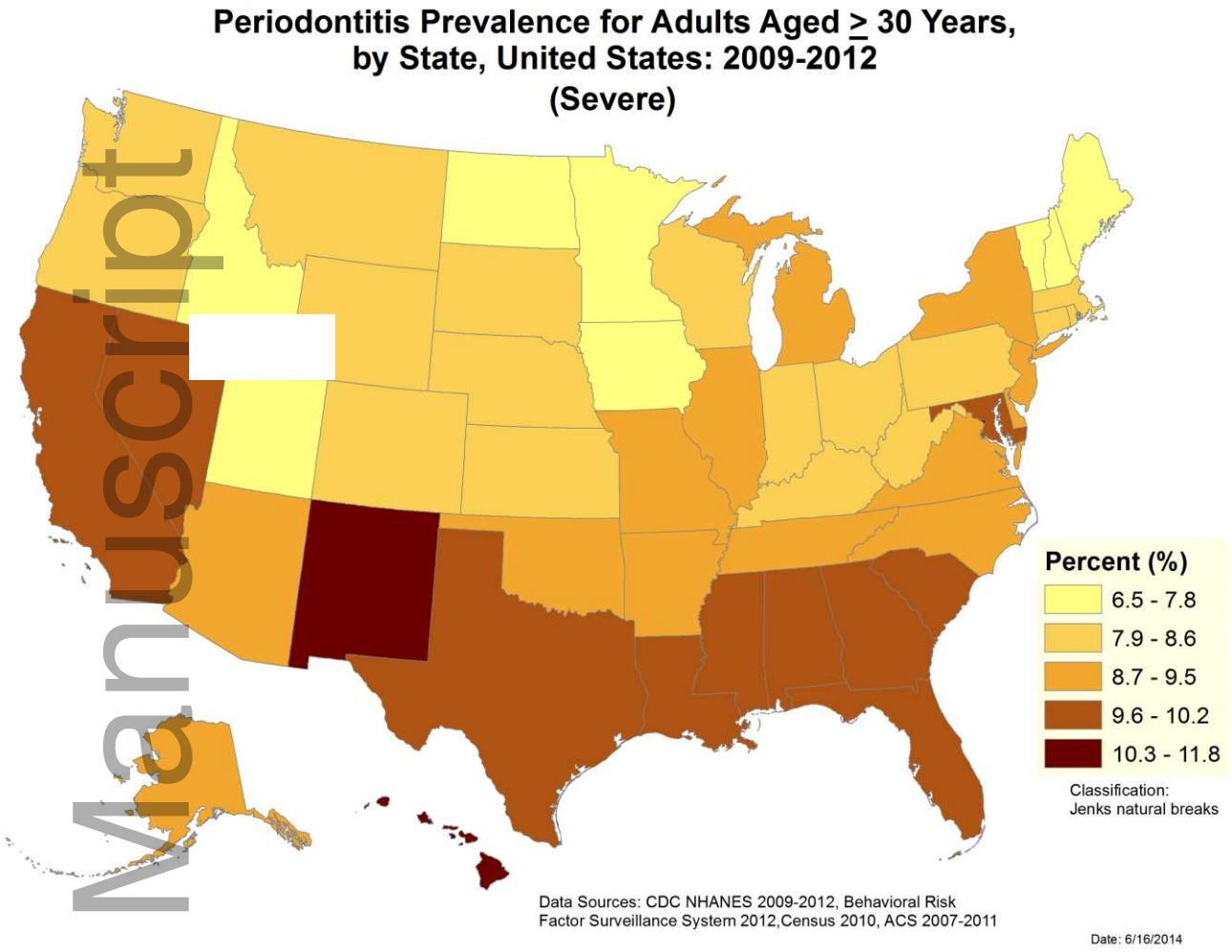

Figure Legends

Fig. 1. Prevalence of total, severe, and non-severe periodontitis in dentate adults aged 30 – 79 years – NHANES 2009 - 2014 (N = 10,683).

Total (any) periodontitis: severe, moderate, or mild periodontitis; non-severe periodontitis: moderate or mild periodontitis.

Fig. 2. Prevalence of total, severe, and non-severe periodontitis by age group in dentate adults aged 30 – 79 years – NHANES 2009 - 2014 (N = 10,683).
Total (any) periodontitis: severe, moderate, or mild periodontitis; non-severe periodontitis: moderate or mild periodontitis.

Fig. 3. Prevalence of total, severe, and non-severe periodontitis by smoking status in dentate adults aged 30 – 79 years – NHANES 2009 - 2014 (N = 10,683).
Total (any) periodontitis: severe, moderate, or mild periodontitis; non-severe periodontitis: moderate or mild periodontitis.

Fig. 4. Relative risk (RR) for severe periodontitis in dentate adults aged 30 – 79 years by age group, sex, race/ethnicity, cigarette smoking habits, diabetes status, and obesity status – NHANES 2009 - 2014 (N = 10,683).
The following groups were used for comparison, that is, they were assigned the RR value of 1: Age 30 – 44 years (age group), female (sex), non-Hispanic white (race/ethnicity), never smoker (cigarette smoking habits), no diabetes/normoglycemic (diabetes status), and normal weight.

Fig. 5. Estimates of prevalence of total periodontitis among dentate adults aged 30–79 years by (a) states, (b) congressional districts, (c) counties, and (d) census tracts – NHANES 2009 – 2012.
Total (any) periodontitis: severe, moderate, or mild periodontitis. [15]
Data sources: CDC National Health and Nutrition Examination Survey (NHANES) 2009–2012, US census 2010, and Behavioral Risk Factor Surveillance System 2012.

Fig. 6. Estimates of prevalence of severe periodontitis among dentate adults aged 30–79 years in US states – NHANES 2009 – 2012. [15]
Data sources: CDC National Health and Nutrition Examination Survey (NHANES) 2009–2012, US census 2010, Behavioral Risk Factor Surveillance System 2012, and American Community Survey 2007 – 2011.