Journal of
Dental Research

Impact of Dental Diseases on Quality-Adjusted Life Expectancy in US Adults

Journal:	*Journal of Dental Research*
Manuscript ID	JDR-18-0887.R1
Manuscript Type:	Research Reports
Date Submitted by the Author:	n/a
Complete List of Authors:	Matsuyama, Yusuke; Tokyo Medical and Dental University (TMDU), Department of Global Health Promotion; Japan Society for the Promotion of Science; University College London, Epidemiology and Public Health Tsakos, Georgios; University College London, Department of Epidemiology and Public Health Listl, Stefan; Radboud university medical center, Department of Quality and Safety of Oral Healthcare; Heidelberg University Hospital, Department of Conservative Dentistry – Section for Translational Health Economics Aida, Jun; Tohoku University Graduate School of Dentistry, Department of International and community oral health Watt, Richard; University College London, , Department of Epidemiology and Public Health
Keywords:	Quality-of-life, Dental public health, Caries, Periodontal disease(s)/periodontitis, Edentulous/edentulism, Epidemiology
Abstract:	Comparing the burden of dental conditions to other health outcomes provides useful insight for public policy. We aimed to estimate quality-adjusted life expectancy (QALE) loss due to dental conditions in the US adult population. Social inequalities in QALE loss by dental conditions were also examined. Data from three cross-sectional waves of the National Health and Nutrition Examination Survey (NHANES waves 2001-2002, 2003-2004, and 2011-2012), were pooled and analyzed. The average age of study participants (n = 9,445) was 48.4 years. Disutility scores were derived from self-rated health, the numbers of physically unhealthy days, mentally unhealthy days, and days with activity limitation, employing a previously published algorithm. The associations between the disutility scores and the numbers of decayed teeth, missing teeth, and periodontitis were examined by multiple linear regression stratified by age groups (20–39, 40–59, and ≥60 years old), adjusted for other covariates (age, sex, wave-fixed effect, educational attainment, smoking, and diabetes). The QALE loss due to dental conditions at the age of 20 was estimated using life tables. Decayed and missing teeth, but not periodontitis, were associated with a larger disutility score. The coefficient for decayed teeth was larger among the older population, whereas that of missing teeth was smaller among them. The estimated QALE loss was 0.43 years (95% CI: 0.28, 0.59), which reached 5.3% of QALE loss (8.15 years; 95% CI; 8.03, 8.27) due to overall morbidity.

	There were clear social gradients in QALE loss by dental conditions across the life course, and people with high school or less education had 0.32 years larger QALE loss in total compared with people with college or more education. This study suggests that improvements in people's dental health may yield substantial gains in population health and wellbeing. The necessity of more comprehensive public health strategies is highlighted.

Impact of Dental Diseases on Quality-Adjusted Life Expectancy in US Adults

Yusuke Matsuyama [1, 2, 3], Georgios Tsakos [3], Stefan Listl [4,5], Jun Aida [6], and Richard G. Watt [3]

Author affiliations

1) Department of Global Health Promotion, Tokyo Medical and Dental University (TMDU), Bunkyo-ku, JP

2) Research Fellow of Japan Society for the Promotion of Science

3) Department of Epidemiology and Public Health, University College London, London, UK

4) Department of Quality and Safety of Oral Healthcare, Radboud university medical center, Nijmegen, NL

5) Department of Conservative Dentistry – Section for Translational Health Economics, Heidelberg University Hospital, Germany

6) Department of International and Community Oral Health, Tohoku University Graduate School of Dentistry, Sendai, Japan

Corresponding author

Yusuke Matsuyama, Ph.D., Department of Global Health Promotion, Tokyo Medical and Dental University (TMDU), Bunkyo-ku, JP, Tel: +44 (0) 7 9996 28145; Email: matsuyama-thk@umin.org

Abstract word count: 298

Total word count: 3,179/3,200

Number of figures/tables: 5

Number of references: 37

Keywords

Quality-of-life, Dental public health, Epidemiology, Caries, Periodontal disease(s)/periodontitis, Edentulous/edentulism

Abstract

Comparing the burden of dental conditions to other health outcomes provides useful insight for public policy. We aimed to estimate quality-adjusted life expectancy (QALE) loss due to dental conditions in the US adult population. Social inequalities in QALE loss by dental conditions were also examined. Data from three cross-sectional waves of the National Health and Nutrition Examination Survey (NHANES waves 2001-2002, 2003-2004, and 2011-2012), were pooled and analyzed. The average age of study participants (n = 9,445) was 48.4 years. Disutility scores were derived from self-rated health, the numbers of physically unhealthy days, mentally unhealthy days, and days with activity limitation, employing a previously published algorithm. The associations between the disutility scores and the numbers of decayed teeth, missing teeth, and periodontitis were examined by multiple linear regression stratified by age groups (20–39, 40–59, and ≥60 years old), adjusted for other covariates (age, sex, wave-fixed effect, educational attainment, smoking, and diabetes). The QALE loss due to dental conditions at the age of 20 was estimated using life tables. Decayed and missing teeth, but not periodontitis, were associated with a larger disutility score. The coefficient for decayed teeth was larger among the older population, whereas that of missing teeth was smaller among them. The estimated QALE loss was 0.43 years (95% CI: 0.28, 0.59), which reached 5.3% of QALE loss (8.15 years; 95% CI; 8.03, 8.27) due to overall morbidity. There were clear social gradients in QALE loss by dental conditions across the life course, and people with high school or less education had 0.32 years larger QALE loss in total compared with people with college

or more education. This study suggests that improvements in people's dental health may yield substantial gains in population health and wellbeing. The necessity of more comprehensive public health strategies is highlighted.

Background

Dental diseases are highly prevalent worldwide (Kassebaum et al. 2017) and substantially affect quality of life (Haag et al. 2017). They are chronic and cumulative in nature (Heilmann et al. 2015) and rapidly increasing across the life course (Kassebaum et al. 2017). The trajectory of dental status is socially-patterned, whereby people from lower socioeconomic position are more likely to have worse dental status at various stages of life (Nicolau et al. 2007; Watt et al. 2015; Steele et al. 2015). Providing a comprehensive picture of the dynamics and social distribution of the health burden due to various dental conditions would provide a unique perspective for shaping public health policy.

Comparing various health outcomes on a single scale is important to evaluate the relative impact of different diseases in society and to prioritize the allocation of healthcare resources. One way to make such comparisons is facilitated by the concept of Quality-Adjusted Life Years (QALY) which represents population health by considering the duration and quality of life. A QALY is calculated by multiplying the duration of time spent with a certain health status and the utility score, an indicator of various health states based upon population preference, whereby death is scored as 0 and full health as 1 (Whitehead and Ali 2010; Neumann and Cohen 2018). Thus, one QALY indicates spending a year in the hypothetical "perfect" or "the most desirable" health state (Neumann and Cohen 2018). The QALY can also be summarized in a lifetime horizon indicating expected duration and quality of remaining life at the specific age, that is, quality-adjusted life expectancy (QALE) (Rosenberg et al. 1999).

QALE may also vary between different socioeconomic groups; the gradients in QALE have been reported with the difference of 11 years at birth by multiple deprivation in the UK (Love-Koh et al. 2015) and 8 years at 25 years of age by educational attainment in the Netherlands (Gheorghe et al. 2016). However, to the best of our knowledge, no studies have reported the dental-related QALE loss and the extent of related social inequalities.

The present study aimed to estimate QALE loss due to decayed teeth, missing teeth, and periodontitis and its social pattern in the US adult population. These three dental conditions were selected because they represent the three most prevalent dental conditions (Kassebaum et al. 2017). Our estimate in the present study does not include other oral conditions such as oral cancer.

Methods

Data source

Our analyses are based on pooled cross-sectional data from three waves of the National Health and Nutrition Examination Survey (NHANES waves 2001-2002, 2003-2004, and 2011-2012). The NHANES survey employs a stratified multistage probability sampling of the civilian non-institutionalized population of the US and collects data through interviews and clinical examinations. More detail about the survey has been reported elsewhere (Centers for Disease Control and Prevention 2012). Participants aged ≥20 years who completed the dental examination and without missing information on the variables were included in the analyses (Figure 1). The present

study was based on analyses of secondary anonymous data and no ethics approval was required.

Variables

The dependent variable was disutility score, which was derived from answers on self-rated health and numbers of physically unhealthy days, mentally unhealthy days, and days with activity limitation during the past 30 days. These four variables were mapped to the EQ-5D index (Brooks 1996), a scale of health utility ranging from 0 (death) to 1 (perfect health), employing a previously published algorithm (Jia et al. 2011). The algorithm has been validated using representative samples of the US adult population, and the bias compared with the actual EQ-5D scale was estimated to be less than 1% (Jia et al. 2011). The mapped EQ-5D utility scores were subtracted from 1 and used as a continuous variable indicating disutility to estimate dental conditions' burden directly. The detail of this procedure is described in Appendix 1.

The explanatory variables were numbers of decayed teeth, missing teeth due to dental diseases, and teeth with periodontitis. Third molars were not included since their periodontal status was not examined. Periodontitis was defined by ≥3 mm of loss of attachment and ≥4 mm of pocket depth on the same periodontal sites (Centers for Disease Control and Prevention 2004). Full-mouth assessment was conducted for periodontal disease in the wave 2011-2012, while three facial sites in two randomly selected quadrants were assessed in the former two waves. To consider the difference, information on periodontitis in the wave 2011-2012 was also randomly selected in the present study.

Age (continuous), sex (men, women), educational attainment (high school or less, less than college, college or more), smoking status (never smoker, former smoker, current smoker), diabetes (yes, no), and survey-wave-fixed effects were adjusted for.

Statistical analyses

We employed a three-step approach to estimate QALE loss. First, the associations between dental conditions and disutility score were examined by multiple linear regression models: unadjusted (model 1), adjusted for all covariates separately for each dental condition (model 2), and adjusted for all covariates and the three variables on dental conditions included together (model 3). The regression models were stratified by age group (20–39, 40–59, and ≥60 years-old) and sampling weight was applied.

Second, to describe the impact of dental conditions in the US population, average disutility due to dental conditions for every five years of age was calculated by multiplying the coefficients in model 3 and the average number of decayed teeth, missing teeth, and periodontitis in the respective age group.

Third, sex-, educational attainment-, and disease-specific QALE loss at the age of 20 was estimated by combining the estimation at the step 2 and the information on life tables for the US population in 2011 (Xu et al. 2015). The detail of this procedure is described in Appendix 2. QALE loss due to overall morbidity was also estimated in order to assess how much of it was due to dental

conditions.

We used STATA MP version 15.1 (Stata Corp., College Station, TX, USA) for all analyses and followed STROBE guidelines.

Results

In total, 9,445 participants (average age = 48.4 years) were included in the analyses (Figure 1). Table 1 describes the demographic characteristics of the respondents. Higher disutility scores were observed among the older participants, women, those with lower educational attainment, smokers, and those with diabetes. Appendix Table 1 shows the distribution of the variables used to derive the disutility score.

Table 2 shows the results from the regression analyses. Decayed teeth and missing teeth were significantly associated with a higher disutility score in all age groups, while the association between disutility score and periodontitis was not significant among those aged 20–39 years and ≥60 years (model 1). The associations between decayed teeth and the disutility score among those aged 20–39 years and periodontitis among the 40–59 year-olds were not significant after adjusting for covariates (model 2). Including all three dental conditions together did not affect the estimates (model 3). Overall, the coefficient on decayed teeth was larger among the older population, while that of missing teeth was smaller among them.

Figure 2 illustrates the average of disease-specific disutility at every five years of age by

educational attainment. The total disutility increased with aging until the age of 60 years mainly due to increased disutility with age from missing teeth. The bars for periodontitis were below 0, representing negative but not significant coefficients (Table 2, model 3). There was a clear social gradient with participants with lower educational attainment having larger disutility at all stages of life.

Table 3 and Appendix Figure 1 summarize the estimated QALE loss at the age of 20. The average QALE loss was 0.43 years (95% confidence interval, CI: 0.28, 0.59), which represents 5.3% in QALE loss due to overall morbidity (8.15 years; 95% CI; 8.03, 8.27). The QALE loss due to dental conditions and the percentage due to overall morbidity by educational strata was 0.57 (6.5%), 0.38 (5.2%), and 0.25 (3.2%) for high school or less, less than college, and college or more, respectively. A social gradient in the total QALE loss by educational attainment was observed and the absolute difference between people educated up to high school level or lower and those who with college or more education was 0.32 years. The QALE loss due to dental conditions shared higher proportion of QALE loss due to overall morbidity in lower educated group (Appendix Figure 1).

Discussion

This study is the first to report the contribution of dental conditions to QALE loss. Decayed teeth and missing teeth were significantly associated with disutility, while periodontitis was not. The marginal effect of one untreated decayed tooth on the disutility score was higher among the older population,

while that of one missing tooth was lower among them. The QALE loss at the age of 20, which represents a lifetime burden of dental conditions from that age onwards, was estimated to be 0.43 years, representing 5.3% of QALE loss due to overall morbidity. A clear social gradient in QALE loss due to dental conditions across life course was observed. Dental conditions shared larger proportion of QALE loss due to overall morbidity among lower educated people, suggesting that dental conditions have relatively higher impact among lower socioeconomic group.

The impact of dental health on QALE can be put into context when compared to the respective estimates for other health outcomes. At a population level, QALE loss is reported to be 1.9 years for diabetes, 1.2 years for heart disease, 1.2 years for obesity/overweight, and 1.9 years for smoking (Jia, Zack and Thompson 2013; Jia, Matthew M. Zack, et al. 2016; Jia, Zack, Thompson, et al. 2013). The difference in QALE between those with/without depression is reported to be 28.9 years (Jia, Matthew M Zack, et al. 2016); however, population-level QALE loss for depression considering the prevalence has not been reported. As the dental-related QALE loss (0.43 years) reached approximately a third or fourth of these major causes of health burden, the burden of dental conditions on quality of life is substantial although they are somewhat neglected in public health policies (Allukian Jr 2008). Distributional aspect of healthcare resource allocation in society needs to be assessed considering the obvious social gradient in dental-related QALE loss and that larger share of dental-related QALE loss among lower socioeconomic population. Policies should follow the proportionate universalism principle (Marmot et al. 2010).

Social gradients in oral health have been reported in both clinical and subjective outcomes (Sheiham et al. 2011). The pattern of the gradient is complex, and it varies by socioeconomic and oral health indicators and countries. For example, a study in the UK reported that the difference in caries prevalence by income were greater in the younger age group, whereas differences by income in missing teeth increased with aging (Steele et al. 2015). The gradient could be narrower in the countries like the UK where dental healthcare is covered by universal health coverage (Guarnizo-Herreño et al. 2015). On the other hand, water fluoridation is widely established in the US and this could contribute to a reduction in inequalities in QALE loss due to dental caries and possibly tooth loss. However, 33% of adults and 12% of children in the US did not have dental insurance in 2013 (Nasseh and Vujicic 2015). Absence of dental insurance is a barrier to access routine dental care, and might have resulted in leaving caries untreated. Ensuring access to dental care for the entire population may at least partially reduce the burden of dental conditions. Several studies reported that social gradients in edentulism in the US have been narrowing, whereas that in untreated decay and the number of missing teeth have been widening (Wu et al. 2014; Farmer et al. 2016). The social gradient in the present study in QALE loss for each age group widened until early-older age, and then it remained stable for those aged 60 years or older. The widening gradient was provided by disutility from the number of missing teeth, suggesting that the social pattern in total dental health burden is driven by accumulating moderate differences (e.g., untreated caries or one additional missing tooth) rather than total tooth loss occurring later in life. Policies focusing on preventing

moderate suboptimal dental condition starting from earlier stages of life could reduce social inequalities in dental-related QALE loss (e.g. extending years of education (Matsuyama et al. 2018) and/or taxing on sugar sweetened beverages/foods (Colchero et al. 2016)).

The effect size of missing teeth was smaller among the older population, but that of decayed teeth was larger among them. This suggests that older people could have adapted and become more tolerant of tooth loss (MacEntee et al. 1997). A study reporting an inverse association between aging and OHIP-14 score among adults with clinical conditions (Slade and Sanders 2011) would support this adaptation. The age-difference in decayed teeth could be explained by its severity: the number of untreated surfaces per one untreated tooth was higher among older people (results not shown). The non-significant association between periodontitis and disutility is in line with a systematic review reporting that the impact of periodontal disease on the general quality of life was inconclusive (Haag et al. 2017). It should be noted that QALE is not the only criterion to determine a condition to be prevented/treated; and periodontal diseases, as a 'silent' disease, should also be prioritized to reduce the resulting tooth loss.

A few population studies have estimated utility scores for dental conditions though none of them have reported QALE loss. Having gingivitis and ≥6 mm of loss of attachment were associated with lower EQ-5D scores by 0.001 and 0.012, respectively; however, confounding factors have not been adjusted for (Brennan et al. 2007). Jamieson et al. reported 0.037 lower EQ-5D score for people with <21 teeth compared to those with 21 or more teeth among the Australian population (Jamieson

et al. 2017). The association reported in that study is larger than our result. This might be because the study population was healthier in the Australian study (average disutility score =0.09) than the present study (average disutility score =0.14). Dental conditions might have a larger impact on quality of life among healthier populations.

Disability-adjusted life years (DALY) is another metric to evaluate and compare different diseases' impact on the population. The disability weights for symptomatic caries, total tooth loss, and severe periodontal disease have been reported as 0.010, 0.067, and 0.007, respectively (Salomon et al. 2015), which were larger than the coefficients from our regression analyses. The DALY for all oral conditions in the US was estimated at 0.003 years per person in 2015 (Kassebaum et al. 2017). Although our estimate focused on three dental conditions, our estimate of QALE was much larger than the DALY estimation. There are some potential explanations for these differences. First, disability weights have a predominantly functional focus on each oral condition (e.g. "a toothache, which causes some difficulty eating" for untreated symptomatic caries and "great difficulty in eating meat, fruits, and vegetables" for total tooth loss (Kassebaum et al. 2017)); however, the social aspect is also an important pathway linking oral conditions and general quality of life (Allen 2003). The utility score focuses on impact to overall quality of life, which is a wider construct and could also include social aspects of oral health. Our additional analyses showed that "feeling embarrassed because of mouth" explained the considerable extent of the association between missing teeth and disutility score (Appendix Table 2). Also, a systematic review reported that loss of anterior teeth had

a larger impact on quality of life than posterior teeth (Gerritsen et al. 2010). Second, the criteria of dental conditions were more extreme when estimating disability weights than the present study. This might also underestimate the burden of dental conditions as they affect considerably the quality of life of people before these excessive thresholds; e.g., tooth loss in general (rather than total tooth loss) has been shown to negatively impact on the oral health-related quality of life (Gerritsen et al. 2010). Furthermore, our additional analyses showed that the marginal effect of one additional missing tooth was not statistically significant after a person lost >8 teeth, which corresponds to losing functional dentition (Appendix Figure 2). This suggests the importance of capturing the burden of moderate but more prevalent dental problems. Third, disability weights are estimated from the questionnaire survey for the general population including people with and also without dental problems. People without dental problems might underestimate the potential burden of it. Another explanation is related to methodological differences, such as age weighting in the DALY estimations, where young or older populations have a lower weight.

This study has some limitations. First, our analyses were based on pooled data from three cross-sectional surveys, thus, our results could partly be due to reverse causation. There were some differences in the dental assessment procedure by waves, e.g. partial mouth periodontal assessment was conducted to people aged ≥18 years old in the waves 2001 and 2003, while full-mouth periodontal assessment was conducted to people aged ≥30 years old. Accordingly, the participants aged between 20 and 29 were from waves 2001 or 2003. Also, there could be confounders that we

did not address, for example, deprivation could be associated with both dental conditions and disutility scores, and this may go beyond the influence of educational attainment (Locker 2000). Second, the study population was sampled from non-institutionalized people, and those who had a certain medical condition were excluded from the clinical examination. Note that our analysis applies only to the impacts of caries, periodontitis, and tooth loss but not to other oral conditions such as oral cancer. The impact of oral conditions would be larger if those less healthy population groups and additional oral health conditions were included. Our study may therefore be considered to provide only lower bound estimates for the impact of oral conditions on people's quality of life. Third, we used continuous variables for dental conditions. The association between periodontitis and disutility score could be underestimated as we used the information from the partial-mouth assessment. However, our sensitivity analyses using full-mouth assessment information in 2011 also showed an insignificant association between periodontitis and disutility score (Appendix Table 3). Sensitivity analyses indicated that categorized clinical variables would reveal similar findings (Appendix Table 4). Smoking and diabetes are mainly associated with periodontitis but not dental caries. The model without adjusting for these covariates showed similar result (Appendix 5). Fourth, we used the data originating from the years 2001 to 2012. Our estimates might not fully reflect recent improvements in dental conditions, while social inequalities in dental diseases have continued to widen (Rozier et al. 2017). This may imply that the overall societal burden of dental diseases on people's quality of life may not necessarily be lower if estimated on basis of more recent data. Fifth, our dependent

variable, disutility score, was derived from the questions on unhealthy days and self-rated health. These questions might not capture all aspects of dental problems. In this sense, QALE loss due to dental conditions in the present study would be underestimated.

Conclusion

This study estimated dental-related quality-adjusted life expectancy (QALE) loss in the US adult population. Population health is certainly compromised by dental conditions and obvious social gradients at all age groups exist. The study findings highlight the necessity for multi-sectoral public health strategies across the life-course to promote oral health and tackle oral health inequalities.

Acknowledgment

The authors gratefully acknowledge the participants in the NHANES surveys. This work was supported by grants from the Grant-in-Aid for JSPS Research Fellow (17J05974). The authors declare no potential conflicts of interest in relation to this study.

References

Allen PF. 2003. Assessment of oral health related quality of life. Health Qual. Life Outcomes 1:40.

Allukian Jr M. 2008. The Neglected Epidemic and the Surgeon General's Report: A Call to Action for Better Oral Health. Am. J. Public Health 98(Suppl 1):82–85.

Brennan DS, Spencer AJ, Roberts-Thomson KF. 2007. Quality of life and disability weights associated with periodontal disease. J. Dent. Res. 86(8):713–717.

Brooks R. 1996. EuroQol: the current state of play. Health Policy. 37(1):53–72.

Centers for Disease Control and Prevention. 2012. National Health and Nutrition Examination Survey (NHANES) Oral Health Examiners Manual.

Centers for Disease Control and Prevention. 2004. Trends in Oral Health Status: United States, 1988–1994 and 1999–2004.

Colchero MA, Popkin BM, Rivera JA, Ng SW. 2016. Beverage purchases from stores in Mexico under the excise tax on sugar sweetened beverages: observational study. BMJ 352:h6704.

Farmer J, McLeod L, Siddiqi A, Ravaghi V, Quiñonez C. 2016. Towards an understanding of the structural determinants of oral health inequalities: A comparative analysis between Canada and the United States. SSM - Popul. Heal. 2:226–236.

Gerritsen AE, Allen PF, Witter DJ, Bronkhorst EM, Creugers NHJ. 2010. Tooth loss and oral health-related quality of life: a systematic review and meta-analysis. Health Qual. Life Outcomes 8:126.

Gheorghe M, Wubulihasimu P, Peters F, Nusselder W, Van Baal PHM. 2016. Health inequalities in the Netherlands: Trends in quality-adjusted life expectancy (QALE) by educational level. Eur. J. Public Health 26(5):794–799.

Guarnizo-Herreño CC, Tsakos G, Sheiham A, Marmot MG, Kawachi I, Watt RG. 2015. Austin Powers bites back: A cross sectional comparison of US and English national oral health surveys. BMJ 351:h6543.

Haag DG, Peres KG, Balasubramanian M, Brennan DS. 2017. Oral Conditions and Health-Related Quality of Life: A Systematic Review. J. Dent. Res. 96(8):864–874.

Heilmann A, Tsakos G, Watt RG. 2015. Oral Health Over the Life Course. In *A Life Course Perspective on Health Trajectories and Transitions*. New York, NY: Springer International Publishing, pp. 39–59.

Jamieson L, Brennan D, Peres MA, Luzzi L, Miller C, Bowden J, McCaffrey N. 2017. Having fewer than 21 teeth associated with poorer general health among South Australians. J. Public Health Dent. 77(3):216–224.

Jia H, Zack MM, Moriarty DG, Fryback DG. 2011. Predicting the EuroQol group's EQ-5D index from CDC's "Healthy Days" in a US sample. Med. Decis. Mak. 31(1):174–185.

Jia H, Zack MM, Thompson WW. 2016. Population-based estimates of decreases in quality-adjusted life expectancy associated with unhealthy body mass index. Public Health Rep. 131(1):177–184.

Jia H, Zack MM, Thompson WW. 2013. The Effects of Diabetes, Hypertension, Asthma, Heart

Disease, and Stroke on Quality-Adjusted Life Expectancy. Value Heal. 2(2):147–185.

Jia H, Zack MM, Thompson WW, Crosby AE, Gottesman II. 2016. Impact of depression on quality-adjusted life expectancy (QALE) directly as well as indirectly through suicide. 50(6):939–949.

Jia H, Zack MM, Thompson WW, Dube SR. 2013. Quality-adjusted life expectancy (QALE) loss due to smoking in the United States. Qual. Life Res. 22(1):27–35.

Kassebaum NJ, Smith AGC, Bernabé E, Fleming TD, Reynolds AE, Vos T, Murray CJL, Marcenes W, Abyu GY, Alsharif U, et al. 2017. Global, Regional, and National Prevalence, Incidence, and Disability-Adjusted Life Years for Oral Conditions for 195 Countries, 1990–2015: A Systematic Analysis for the Global Burden of Diseases, Injuries, and Risk Factors. J. Dent. Res. 96(4):380–387.

Locker D. 2000. Deprivation and oral health: a review. Community Dent. Oral Epidemiol. 28(3):161–169.

Love-Koh J, Asaria M, Cookson R, Griffin S. 2015. The Social Distribution of Health: Estimating Quality-Adjusted Life Expectancy in England. Value Heal. 18(5):655–662.

MacEntee MI, Hole R, Stolar E. 1997. The significance of the mouth in old age. Soc. Sci. Med. 45(9):1449–1458.

Marmot MG, Allen J, Goldblatt P, Boyce T, McNeish D, Grady M, Geddes I, Caan W. 2010. Fair Society, Healthy Lives. The Marmot Review. Strategic review of health inequalities in England post-2010.

Matsuyama Y, Jürges H, Listl S. 2018. The Causal Effect of Education on Tooth Loss: Evidence from UK Schooling Reforms. Am. J. Epidemiol.:[Epub ahead of print].

Nasseh K, Vujicic M. 2015. Dental Benefits Coverage Rates Increased for Children and Young Adults in 2013. Heal. Policy Inst. Res. Brief. Am. Dent. Assoc.(October).

Neumann PJ, Cohen JT. 2018. QALYs in 2018—Advantages and Concerns. Jama 02111:5–6.

Nicolau B, Thomson WM, Steele JG, Allison PJ. 2007. Life-course epidemiology: Concepts and theoretical models and its relevance to chronic oral conditions. Community Dent. Oral Epidemiol. 35(4):241–249.

Rosenberg MA, Fryback DG, Lawrence WF. 1999. Computing population-based estimates of health-adjusted life expectancy. Med. Decis. Mak. 19(1):90–97.

Salomon JA, Haagsma JA, Davis A, de Noordhout CM, Polinder S, Havelaar AH, Cassini A, Devleesschauwer B, Kretzschmar M, Speybroeck N, et al. 2015. Disability weights for the Global Burden of Disease 2013 study. Lancet Glob. Heal. 3(11):e712–e723.

Sheiham A, Alexander D, Cohen L, Marinho V, Moysés S, Petersen PE, Spencer J, Watt RG, Weyant R. 2011. Global oral health inequalities: task group-implementation and delivery of oral health strategies. Adv. Dent. Res. 23(2):259–267.

Slade GD, Sanders AE. 2011. The paradox of better subjective oral health in older age. J. Dent. Res. 90(11):1279–1285.

Steele J, Shen J, Tsakos G, Fuller E, Morris S, Watt R, Guarnizo-Herreño C, Wildman J. 2015. The

interplay between socioeconomic inequalities and clinical oral health. J. Dent. Res. 94(1):19–26.

Watt R, Listl S, Peres M, Heilmann A. 2015. Social inequalities in oral health: from evidence to action. London: International Centre for Oral Health Inequalities Research and Policy.

Whitehead SJ, Ali S. 2010. Health outcomes in economic evaluation: The QALY and utilities. Br. Med. Bull. 96(1):5–21.

Wu B, Hybels C, Liang J, Landerman L, Plassman B. 2014. Social stratification and tooth loss among middle-aged and older Americans from 1988 to 2004. Community Dent. Oral Epidemiol. 42(6):495–502.

Xu J, Kochanek KD, Murphy SL. 2015. National Vital Statistics Reports Deaths : Final Data for 2011. Statistics (Ber). 63(3):135.

Figure legends

Figure 1. Flowchart to obtain respondents for analyses

Figure 2. Average disutility due to oral conditions among US population by age groups; the three graphs in the same age group shows each educational attainment: high school or less (left); less than college (middle); college or more (right)

Table 1. Demographic characteristics of respondents (n = 9,445; non-weighted)

	Number of respondents	Disutility score		Decayed teeth		Missing teeth		Periodontitis [a]	
	n	Mean	SD	Mean	SD	Mean	SD	Mean	SD
NHANES wave									
2001	3,298	0.13	0.09	0.67	1.83	3.37	5.50	0.27	0.96
2003	2,975	0.13	0.09	0.87	1.81	3.83	5.93	0.20	0.83
2011	3,172	0.15	0.11	0.67	1.81	6.96	9.08	0.79	1.81
Age									
20–39	3,352	0.12	0.08	0.94	2.17	1.02	2.77	0.18	0.87
40–59	3,286	0.14	0.11	0.76	1.77	3.99	5.65	0.61	1.59
≥60	2,807	0.15	0.10	0.46	1.30	9.99	9.13	0.51	1.32
Sex									
Men	4,694	0.13	0.09	0.84	1.99	4.70	7.18	0.58	1.55
Women	4,751	0.15	0.10	0.63	1.63	4.74	7.23	0.27	0.98
Education									
High school or less	2,409	0.16	0.11	1.16	2.31	6.90	8.40	0.63	1.58
Less than college	4,725	0.14	0.10	0.75	1.81	4.79	7.13	0.42	1.32
College or more	2,311	0.12	0.08	0.26	0.91	2.30	4.89	0.21	0.85
Smoking status									
Never smoker	5,068	0.13	0.09	0.57	1.47	3.62	6.24	0.29	1.03
Former smoker	2,369	0.14	0.10	0.54	1.50	6.38	8.25	0.44	1.26
Current smoker	2,008	0.16	0.11	1.38	2.63	5.54	7.64	0.75	1.81
Diabetes									
Not diabetes	8,478	0.13	0.09	0.74	1.85	4.15	6.72	0.39	1.26
Diabetes	967	0.18	0.13	0.66	1.51	9.69	9.15	0.68	1.60
Total	9,445	0.14	0.10	0.73	1.82	4.72	7.20	0.42	1.30

a The number of teeth with pocket depth ≥4mm and loss of attachment ≥3mm on the same periodontal site

Table 2. Association between oral condition and disutility score (n =9,445); sampling weight applied.

	Model 1		Model 2		Model 3	
	β	95% CI	β	95% CI	β	95% CI
Age of 20-39						
Decayed teeth	0.0032	0.0012, 0.0051	0.0016	-0.0003, 0.0035	0.0013	-0.0007, 0.0032
Missing teeth	0.0038	0.0022, 0.0054	0.0023	0.0008, 0.0038	0.0021	0.0006, 0.0037
Periodontitis [a]	0.0008	-0.0026, 0.0042	-0.0023	-0.0057, 0.0011	-0.0027	-0.0062, 0.0008
Age of 40-59						
Decayed teeth	0.0079	0.0049, 0.0109	0.0048	0.0017, 0.0079	0.0044	0.0013, 0.0074
Missing teeth	0.0033	0.0024, 0.0042	0.0015	0.0006, 0.0025	0.0014	0.0004, 0.0023
Periodontitis [a]	0.0032	0.0004, 0.0060	-0.0012	-0.0039, 0.0015	-0.0016	-0.0043, 0.0011
Age of ≥60						
Decayed teeth	0.0080	0.0026, 0.0134	0.0059	0.0005, 0.0113	0.0059	0.0005, 0.0113
Missing teeth	0.0017	0.0012, 0.0021	0.0008	0.0003, 0.0013	0.0008	0.0003, 0.0013
Periodontitis [a]	0.0013	-0.0022, 0.0048	0.0004	-0.0030, 0.0038	0.0002	-0.0032, 0.0036

β, non-standardized coefficient, CI, confidence interval

Model 1: crude; each oral condition was separately included

Model 2: adjusted for age, sex, wave fixed effect, education, smoking, and diabetes

Model 3: model 2 +all oral conditions were included together

a The number of teeth with pocket depth ≥4mm and loss of attachment ≥3mm on the same periodontal site

Table 3. Quality-adjusted life expectancy loss due to oral conditions, at the age of 20

	QALE loss (years)									
	Overall morbidity		All oral conditions		Decayed teeth		Missing teeth		Periodontitis [a]	
	Point estimate	95% CI [b]	Point estimate	95% CI [b]	Point estimate	95% CI [b]	Point estimate	95% CI [b]	Point estimate	95% CI [b]
Both										
All	8.15	8.03, 8.27	0.43	0.28, 0.59	0.14	0.07, 0.22	0.31	0.19, 0.45	-0.02	-0.07, 0.03
High school or less	8.71	8.45, 8.95	0.57	0.36, 0.76	0.21	0.10, 0.33	0.39	0.24, 0.56	-0.04	-0.11, 0.03
Less than college	7.32	7.17, 7.48	0.38	0.24, 0.51	0.12	0.06, 0.19	0.28	0.18, 0.40	-0.03	-0.07, 0.02
College or more	7.83	7.56, 8.12	0.25	0.15, 0.35	0.07	0.03, 0.13	0.18	0.10, 0.27	-0.01	-0.04, 0.03
Men										
All	7.35	7.20, 7.51	0.41	0.26, 0.57	0.16	0.08, 0.25	0.29	0.18, 0.41	-0.03	-0.09, 0.03
High school or less	7.69	7.39, 8.00	0.54	0.34, 0.74	0.24	0.12, 0.37	0.35	0.21, 0.50	-0.05	-0.13, 0.04
Less than college	6.56	6.37, 6.78	0.36	0.23, 0.50	0.13	0.06, 0.21	0.26	0.16, 0.37	-0.03	-0.09, 0.03
College or more	7.28	6.97, 7.70	0.26	0.15, 0.37	0.08	0.04, 0.15	0.19	0.10, 0.28	-0.01	-0.05, 0.04
Women										
All	8.96	8.76, 9.16	0.44	0.28, 0.59	0.12	0.06, 0.18	0.34	0.20, 0.48	-0.02	-0.05, 0.02
High school or less	9.88	9.49, 10.31	0.60	0.39, 0.80	0.18	0.09, 0.29	0.45	0.27, 0.63	-0.03	-0.08, 0.02
Less than college	8.11	7.88, 8.34	0.39	0.26, 0.54	0.11	0.05, 0.17	0.31	0.19, 0.43	-0.02	-0.05, 0.02
College or more	8.32	7.94, 8.75	0.22	0.13, 0.32	0.06	0.03, 0.12	0.17	0.10, 0.26	-0.01	-0.03, 0.01

CI, confidence interval, QALE, quality-adjusted life expectancy

a The number of teeth with pocket depth ≥4mm and loss of attachment ≥3mm on the same periodontal site

b Estimated using bootstrapping with 2,000 repetitions

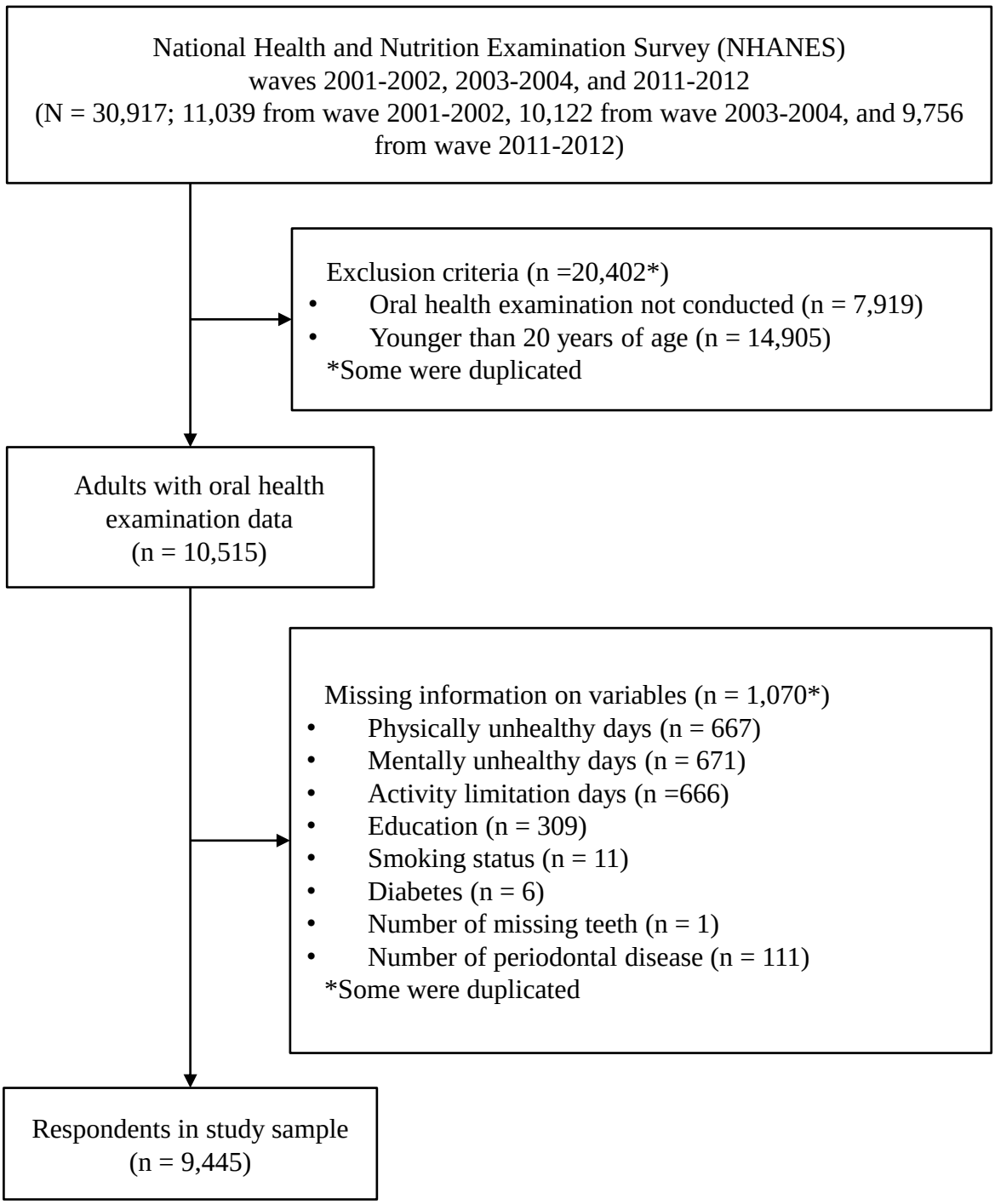


Figure 1. Flowchart to obtain respondents for analyses

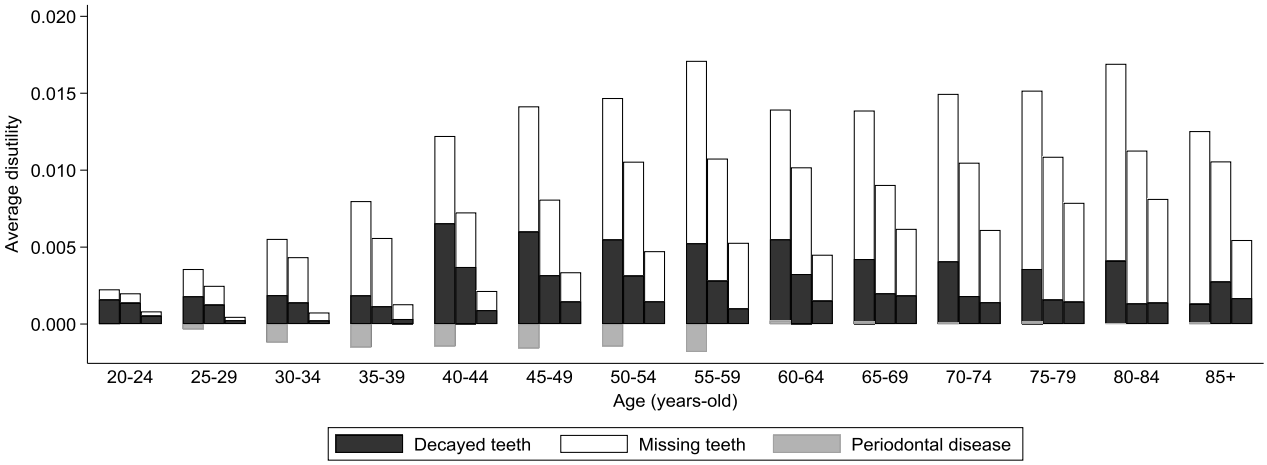


Figure 2. Average disutility due to oral conditions among US population by age groups; the three graphs in the same age group shows each educational attainment: high school or less (left); less than college (middle); college or more (right)

Appendix 1. Algorithm to calculate the disutility score in the US population

Firstly, we employed the algorithm reported by Jia H, Zack MM, Moriarty DG, Fryback DG. 2011. Predicting the EuroQol group's EQ-5D index from CDC's "Healthy Days" in a US sample. Med. Decis. Mak. 31(1):174–185 to calculate utility score from age, self-rated health, the numbers of physically unhealthy days, mentally unhealthy days, and days with the activity limitation by the following equation:

Utility score = 0.7828 + PUD + MUD + ALD + AGE + SRH

Where PUD, MUD, ALD, AGE, and SRH indicate scores for the number of physically unhealthy days, the number of mentally unhealthy days, the number of days with the activity limitation, age (<45, 45-64, 65-74, and ≥75 years old), and self-rated health (excellent, very good, good, fair, and poor), respectively. Each score decrease with aging, reporting poorer self-rated health, spending more physically/mentally unhealthy days or activity limitation days. Every score according to the numbers of unhealthy days, self-rated health, and age is reported in Jia et al. Table 2.

As an example, disutility score for an individual with 65 years of age, 4 days of physically unhealthy days, 5 days of mentally unhealthy days, 8 days of the activity limitation, and good self-rated health, is calculated as:

Utility score = 0.7828 + (–0.0306) + (–0.0282) + (–0.0481) + 0.0111 + 0.1081 = 0.7951

We subtracted the utility score from 1 to derive disutility score. Thus, the disutility score for above individual is:

Disutility score = 1 – utility score = 1 – 0.7951 = 0.2049.

Appendix 2. Procedure to estimate Quality Adjusted Life Expectancy (QALE) in the US population

We employed the method used in previous studies (e.g., Jia H, Zack MM, Thompson WW. 2016. Population-based estimates of decreases in quality-adjusted life expectancy associated with unhealthy body mass index. Public Health Rep. 131(1):177–184; Love-Koh J, Asaria M, Cookson R, Griffin S. 2015. The Social Distribution of Health: Estimating Quality-Adjusted Life Expectancy in England. Value Heal. 18(5):655–662.).

The QALE at the age of 20 years was estimated through the following equation:

$$QALE\ loss_{dxes} = \frac{\sum_{x}^{x+5}(L_{dxes} * \overline{DisU}_{dxes})}{I_{xes}}$$

$QALE\ loss_{dxes}$: QALE loss due to disease d at the start of age interval x; educational group e; sex s; the last age interval z

L_{dxes}: person-years lived in the interval

I_{dxes}: Number of surviving to the age of x

$\overline{DisU}_{dxes}$: Average disutility due to dental conditions at the interval, estimated from the regression analyses

Individuals dying during an age interval were assumed to have survived half of the length of the interval. Since direct information on life tables by educational attainment is not reported, we assumed that relative difference in mortality rate by educational attainment was constant with aging. In the present study, the confidence intervals of QALE loss were estimated by bootstrapping with 2,000 repetitions.

Appendix Table 1. Distributions of variables used to obtain disutility score (n = 9,445)

	Number of respondents	Physically unhealthy days		Mentally unhealthy days		Inactive days		Self-rated health				
								Excellent	Very good	Good	Fair	Poor
	n	Mean	SD	Mean	SD	Mean	SD	col %	col %	col %	col %	col %
NHANES wave												
2001	3,298	3.42	7.47	3.43	7.36	1.48	5.16	40.7	37.9	32.3	31.9	30.1
2003	2,975	3.29	7.35	3.36	7.24	1.47	5.19	32.9	31.8	31.4	30.9	26.8
2011	3,172	3.83	8.05	3.81	7.86	2.00	6.14	26.4	30.3	36.3	37.2	43.1
Age												
20–39	3,352	2.49	6.03	3.74	7.48	1.29	4.60	43.3	39.4	35.3	26.3	16.4
40–59	3,286	3.79	7.96	3.97	7.88	1.94	5.99	32.2	35.2	34.3	36.4	37.9
≥60	2,807	4.43	8.75	2.78	6.98	1.75	5.93	24.5	25.4	30.3	37.3	45.7
Sex												
Men	4,694	3.06	7.28	2.79	6.81	1.49	5.39	52.2	50.5	50.0	47.0	42.4
Women	4,751	3.98	7.95	4.27	8.05	1.81	5.65	47.8	49.5	50.0	53.0	57.6
Education												
High school or less	2,409	4.51	8.76	4.11	8.27	2.08	6.25	15.4	13.3	26.5	48.4	49.4
Less than college	4,725	3.44	7.52	3.56	7.41	1.68	5.62	45.6	53.4	53.2	41.6	43.1
College or more	2,311	2.66	6.41	2.88	6.74	1.14	4.35	39.0	33.3	20.3	10.0	7.4
Smoking status												
Never smoker	5,068	3.17	7.16	3.02	6.92	1.34	4.89	63.7	56.1	50.6	50.0	45.0
Former smoker	2,369	3.72	8.00	3.23	7.20	1.75	5.86	23.1	25.8	26.0	23.0	26.8
Current smoker	2,008	4.16	8.28	5.20	8.86	2.33	6.48	13.2	18.2	23.3	27.0	28.3
Diabetes												
Not diabetes	8,478	3.25	7.29	3.41	7.31	1.51	5.22	97.6	95.4	89.3	78.3	69.9
Diabetes	967	5.91	9.89	4.60	8.92	2.92	7.60	2.4	4.6	10.7	21.7	30.1
Total	9,445	3.52	7.64	3.53	7.49	1.65	5.52	100.0	100.0	100.0	100.0	100.0

SD, standard deviation

Appendix Table 2. Mediation of NHANES-OHIP items on the associations between oral conditions and disutility score; n =2,968, wave 2003–2004 only, all age group, non-weighted results

	Model 1			Model 2			
	β.	95% CI		β	95% CI		% reduction
Decayed teeth	0.0042	0.0023	0.0061	0.0034	0.0016	0.0053	-19.0
Missing teeth	0.0007	0.0000	0.0014	0.0005	-0.0001	0.0012	-28.6
Periodontitis	-0.0010	-0.0049	0.0030	-0.0007	-0.0046	0.0033	-30.0
Aching in the mouth [a]				0.0134	0.0101	0.0167	
Decayed teeth	0.0042	0.0023	0.0061	0.0028	0.0009	0.0046	-33.3
Missing teeth	0.0007	0.0000	0.0014	0.0003	-0.0004	0.0009	-57.1
Periodontitis	-0.0010	-0.0049	0.0030	-0.0013	-0.0052	0.0026	30.0
Felt bad [b]				0.0203	0.0163	0.0242	
Decayed teeth	0.0042	0.0023	0.0061	0.0033	0.0015	0.0052	-21.4
Missing teeth	0.0007	0.0000	0.0014	0.0005	-0.0001	0.0012	-28.6
Periodontitis	-0.0010	-0.0049	0.0030	-0.0008	-0.0047	0.0032	-20.0
Difficulty in working [c]				0.0243	0.0178	0.0308	
Decayed teeth	0.0042	0.0023	0.0061	0.0036	0.0018	0.0055	-14.3
Missing teeth	0.0007	0.0000	0.0014	0.0003	-0.0004	0.0009	-57.1
Periodontitis	-0.0010	-0.0049	0.0030	-0.0008	-0.0047	0.0032	-20.0
Taste affected [d]				0.0280	0.0223	0.0336	
Decayed teeth	0.0042	0.0023	0.0061	0.0031	0.0012	0.0049	-26.2
Missing teeth	0.0007	0.0000	0.0014	0.0002	-0.0004	0.0009	-71.4
Periodontitis	-0.0010	-0.0049	0.0030	-0.0006	-0.0046	0.0033	-40.0
Avoid some food [e]				0.0174	0.0141	0.0207	
Decayed teeth	0.0042	0.0023	0.0061	0.0028	0.0009	0.0046	-33.3
Missing teeth	0.0007	0.0000	0.0014	0.0001	-0.0005	0.0008	-85.7
Periodontitis	-0.0010	-0.0049	0.0030	-0.0008	-0.0047	0.0031	-20.0
Could not eat [f]				0.0204	0.0170	0.0238	
Decayed teeth	0.0042	0.0023	0.0061	0.0031	0.0013	0.0050	-26.2
Missing teeth	0.0007	0.0000	0.0014	0.0004	-0.0003	0.0010	-42.9
Periodontitis	-0.0010	-0.0049	0.0030	-0.0016	-0.0056	0.0023	60.0
Embarrassed [g]				0.0141	0.0108	0.0174	
Decayed teeth	0.0042	0.0023	0.0061	0.0021	0.0003	0.0039	-50.0
Missing teeth	0.0007	0.0000	0.0014	0.0000	-0.0007	0.0006	-100.0
Periodontitis	-0.0010	-0.0049	0.0030	-0.0010	-0.0048	0.0029	0.0
Total score [h]				0.0053	0.0046	0.0061	

β, non-standardized coefficient, CI, confidence interval, OHIP, Oral Health Impact Profile, ref., reference

All models included all oral conditions together and adjusted for age, sex, wave fixed effect, education, smoking, and diabetes

a How often last year had aching in the mouth? (Ranging from never: 0 to very often: 4)
b How often felt bad because of mouth? (Ranging from never: 0 to very often: 4)
c Last year had difficulty in working or job because of mouth (Ranging from never: 0 to very often: 4)
d Last year taste affected because of mouth (Ranging from never: 0 to very often: 4)
e Last year avoid some food because of mouth (Ranging from never: 0 to very often: 4)
f Last year could not eat because of mouth (Ranging from never: 0 to very often: 4)
g Last year embarrassed because of mouth (Ranging from never: 0 to very often: 4)
h Total score of the seven items (Ranging from 0 to 28)

Appendix Table 3. Association between oral condition and disutility score using full-mouth assessment information in the wave 2011; sampling weight applied

	Model 1			Model 2			Model 3		
	Coef.	95% CI		Coef.	95% CI		Coef.	95% CI	
Age of 20-39									
Decayed teeth	0.0050	-0.0008	0.0109	0.0028	-0.0024	0.0079	0.0031	-0.0026	0.0088
Missing teeth	0.0033	0.0011	0.0054	0.0003	-0.0020	0.0025	-0.0003	-0.0028	0.0022
Periodontitis [a]	0.0011	-0.0017	0.0038	-0.0009	-0.0036	0.0018	-0.0013	-0.0043	0.0016
Age of 40-59									
Decayed teeth	0.0070	0.0020	0.0120	0.0031	-0.0022	0.0085	0.0025	-0.0026	0.0076
Missing teeth	0.0038	0.0023	0.0053	0.0021	0.0006	0.0037	0.0020	0.0004	0.0036
Periodontitis [a]	0.0011	-0.0006	0.0028	-0.0013	-0.0029	0.0003	-0.0012	-0.0028	0.0004
Age of ≥60									
Decayed teeth	0.0063	-0.0002	0.0128	0.0044	-0.0016	0.0103	0.0039	-0.0019	0.0097
Missing teeth	0.0019	0.0013	0.0025	0.0012	0.0005	0.0018	0.0012	0.0005	0.0019
Periodontitis [a]	0.0016	-0.0010	0.0043	0.0013	-0.0016	0.0041	0.0017	-0.0011	0.0044

β, non-standardized coefficient, CI, confidence interval
Model 1: crude; each oral condition was separately included
Model 2: model 1 +age, sex, education, smoking, and diabetes
Model 3: model 2 +all oral conditions were included together
a The number of teeth with pocket depth ≥4mm and loss of attachment ≥3mm on the same periodontal site

Appendix Table 4. Sensitivity analyses using categorical variables for missing teeth and periodontitis (n =9,445); sampling weight applied

	Model 1			Model 2			Model 3		
	β	95% CI		β	95% CI		β	95% CI	
Age of 20-39									
Decayed teeth	0.0032	0.0012	0.0051	0.0016	-0.0003	0.0035	0.0017	-0.0003	0.0037
Functional dentition [a]									
Yes	ref.			ref.			ref.		
No	0.0275	0.0061	0.0488	0.0141	-0.0064	0.0345	0.0132	-0.0078	0.0341
Periodontitis [b]									
None	ref.			ref.			ref.		
Moderate	-0.0015	-0.0258	0.0228	-0.0154	-0.0389	0.0081	-0.0205	-0.0436	0.0027
Severe	-0.0004	-0.0126	0.0117	-0.0117	-0.0237	0.0003	-0.0138	-0.0263	-0.0012
Age of 40-59									
Decayed teeth	0.0079	0.0049	0.0109	0.0048	0.0017	0.0079	0.0045	0.0014	0.0076
Functional dentition [a]									
Yes	ref.			ref.			ref.		
No	0.0375	0.0244	0.0507	0.0131	-0.0001	0.0262	0.0102	-0.0030	0.0233
Periodontitis [b]									
None	ref.			ref.			ref.		
Moderate	0.0165	0.0010	0.0320	-0.0013	-0.0165	0.0139	-0.0048	-0.0201	0.0105
Severe	0.0202	0.0049	0.0356	0.0012	-0.0140	0.0164	-0.0004	-0.0157	0.0148
Age of ≥60									
Decayed teeth	0.0080	0.0026	0.0134	0.0059	0.0005	0.0113	0.0057	0.0005	0.0110
Functional dentition [a]									
Yes	ref.			ref.			ref.		
No	0.0289	0.0201	0.0377	0.0150	0.0060	0.0240	0.0147	0.0057	0.0236
Periodontitis [b]									
None	ref.			ref.			ref.		
Moderate	0.0063	-0.0055	0.0181	0.0024	-0.0085	0.0133	0.0005	-0.0102	0.0111
Severe	-0.0017	-0.0155	0.0122	-0.0049	-0.0178	0.0079	-0.0092	-0.0219	0.0035

β, non-standardized coefficient, CI, confidence interval, ref., reference
a defined by having 20 teeth or more
b followed the criteria from CDC-American Academy of Periodontology (Page and Eke, 2007)
Model 1: crude; each oral condition was separately included
Model 2: model 1 +age, sex, wave fixed effect, education, smoking, and diabetes
Model 3: model 2 +all oral conditions were included together

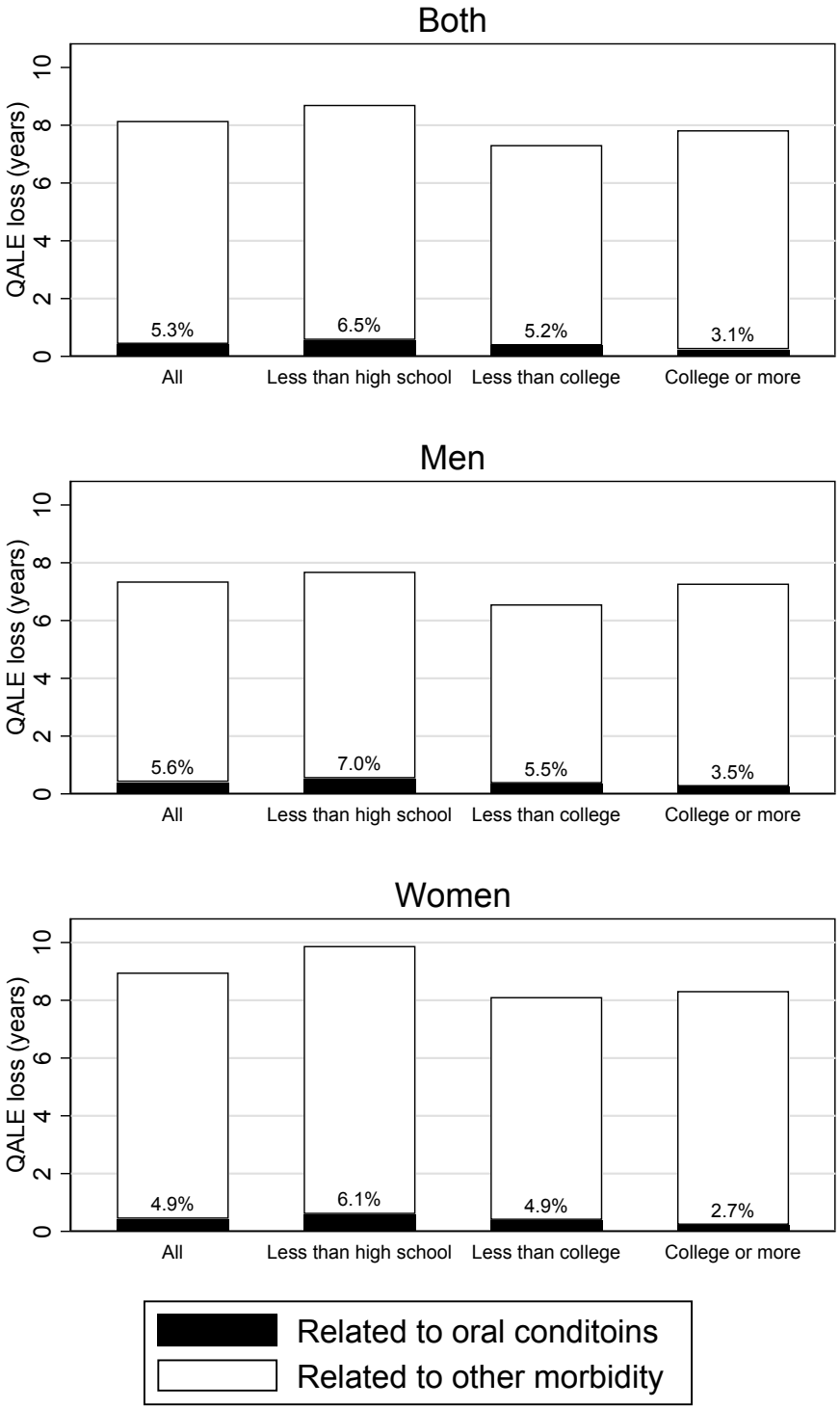
Appendix Table 5. Results with/without adjusting for smoking and diabetes (n =9,445); sampling weight applied.

	Not adjusted for smoking and diabetes		Adjusted for smoking and diabetes (main result)	
	Coef.	95% CI	Coef.	95% CI
Age of 20-39				
Number of untreated caries	0.0018	-0.0002, 0.0039	0.0013	-0.0007, 0.0032
Number of missing teeth	0.0026	0.0011, 0.0042	0.0021	0.0006, 0.0037
Number of teeth with periodontitis	-0.0017	-0.0054, 0.0020	-0.0027	-0.0062, 0.0008
Age of 40-59				
Number of untreated caries	0.0050	0.0019, 0.0081	0.0044	0.0013, 0.0074
Number of missing teeth	0.0021	0.0011, 0.0030	0.0014	0.0004, 0.0023
Number of teeth with periodontitis	0.0000	-0.0028, 0.0027	-0.0016	-0.0043, 0.0011
Age of 60+				
Number of untreated caries	0.0067	0.0013, 0.0121	0.0059	0.0005, 0.0113
Number of missing teeth	0.0012	0.0007, 0.0017	0.0008	0.0003, 0.0013
Number of teeth with periodontitis	0.0011	-0.0023, 0.0045	0.0002	-0.0032, 0.0036

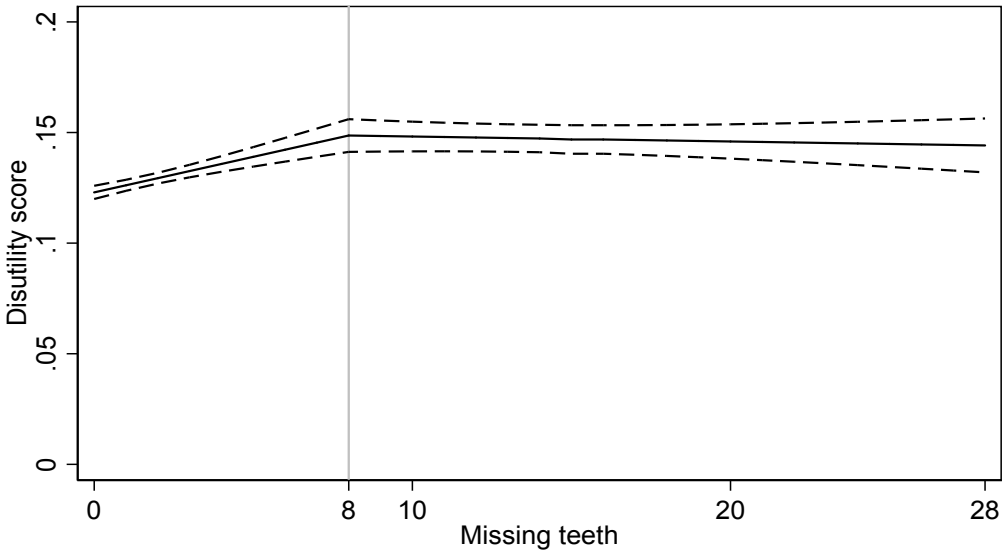
Model 1: adjusted for age, sex, wave fixed effect, education, and all dental conditions together (not adjusted for smoking and diabetes)

Model 2: adjusted for age, sex, wave fixed effect, education, smoking, diabetes, and all dental conditions together (main result)

Appendix Figure 1. Quality-adjusted life expectancy (QALE) loss due to oral conditions and overall morbidity; the figures above black bars indicate the proportion of dental-related QALE loss in QALE loss due to overall morbidity



Appendix Figure 2. Dose-response relationship between the number of missing teeth and disutility score; piecewise linear regression model



Disutility score = .0032 (95% CI: .0021, .0043) * Missing teeth; if Missing teeth <=8
Disutility score = -.0002 (95% CI: -.001, .0005) * Missing teeth; if Missing teeth >8
All age groups together
Adjusted for age, sex, wave fixed effect, education, smoking, and diabetes

STROBE Statement—Checklist of items that should be included in reports of ***cross-sectional studies***

	Item No	Recommendation	Page
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract	3
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found	3
Introduction			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	5
Objectives	3	State specific objectives, including any prespecified hypotheses	6
Methods			
Study design	4	Present key elements of study design early in the paper	6
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	6
Participants	6	(*a*) Give the eligibility criteria, and the sources and methods of selection of participants	6
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	7
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	6
Bias	9	Describe any efforts to address potential sources of bias	8
Study size	10	Explain how the study size was arrived at	6
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	7
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding	8
		(*b*) Describe any methods used to examine subgroups and interactions	8
		(*c*) Explain how missing data were addressed	7
		(*d*) If applicable, describe analytical methods taking account of sampling strategy	8
		(*e*) Describe any sensitivity analyses	16
Results			
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	Figure 1
		(b) Give reasons for non-participation at each stage	Figure 1
		(c) Consider use of a flow diagram	Figure 1
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	10
		(b) Indicate number of participants with missing data for each variable of interest	Figure 1
Outcome data	15*	Report numbers of outcome events or summary measures	10
Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	Table 2

		(*b*) Report category boundaries when continuous variables were categorized	7
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	11
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	16
Discussion			
Key results	18	Summarise key results with reference to study objectives	11
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	16
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	12
Generalisability	21	Discuss the generalisability (external validity) of the study results	14
Other information			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	17

*Give information separately for exposed and unexposed groups.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.