CLINICAL REVIEW

Global Burden of Severe Tooth Loss: A Systematic Review and Meta-analysis

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Abstract: *The goal of the Global Burden of Disease 2010 Study has been to systematically produce comparable estimates of the burden of 291 diseases and injuries and their associated 1,160 sequelae from 1990 to 2010. We aimed to report here internally consistent prevalence and incidence estimates of severe tooth loss for all countries, 20 age groups, and both sexes for 1990 and 2010. The systematic search of the literature yielded 5,618 unique citations. After titles and abstracts were screened, 5,285 citations were excluded as clearly not relevant to this systematic review, leaving 333 for full-text review; 265 publications were further excluded following the validity assessment. A total of 68 studies—including 285,746 individuals aged 12 yr or older in 26 countries—were included in the meta-analysis using modeling resources of the Global Burden of Disease 2010 Study. Between 1990 and 2010, the global age-standardized prevalence of edentate people decreased from 4.4% (95% uncertainty interval: 4.1%, 4.8%) to 2.4% (95% UI: 2.2%, 2.7%), and incidence rate decreased from 374 cases per 100,000 person-years (95% UI: 347, 406) to 205 cases (95% UI: 187, 226). No differences were found by sex in 2010. Prevalence increased gradually with age, showing a steep increase*

around the seventh decade of life that was associated with a peak in incidence at 65 years. Geographic differences in prevalence, incidence, and rate of improvement from 1990 to 2010 were stark. Our review of available quality literature on the epidemiology of tooth loss shows a significant decline in the prevalence and incidence of severe tooth loss between 1990 and 2010 at the global, regional, and country levels.

Key Words: toothless, epidemiology, missing teeth, extracted teeth, global health, edentate.

Introduction

Tooth loss is a complex outcome that reflects an individual's history of dental disease and its treatment by dental services over the life course (Petersen *et al.*, 2005; Baelum *et al.*, 2007). Tooth loss reflects not only dental disease but also patients' and dentists' attitudes, the dentist-patient relationship, the availability and accessibility of dental services, and the prevailing philosophies of dental care (Baelum *et al.*, 2007; Fejerskov *et al.*, 2013). A good understanding of current trends in tooth loss is important for planning dental services and workforce as well as for updating the dental curriculum.

Tooth loss is considered an effective marker of population oral health and is therefore monitored in many countries. However, the epidemiology of tooth loss is not yet fully understood. Previous attempts to synthesize the epidemiology of tooth loss are limited to the developed world (Mojon *et al.*, 2004; Müller *et al.*, 2007) or the elderly (World Health Organization, 2003). Although it is accepted that the prevalence of edentate people has declined in all age groups in many developed countries (Hugoson *et al.*, 2005; Dye *et al.*, 2007; Steele *et al.*, 2012), data from developing and emerging countries are lacking. Moreover, data on the incidence of tooth loss are sparse (Müller *et al.*, 2007). This is further complicated by the quality of epidemiologic data, which vary considerably among surveys and make comparison among countries difficult (Mojon *et al.*, 2004). In addition, the rapidly changing dental health during the past 4 decades indicates that new data are required regularly.

The goal of the Global Burden of Disease (GBD) 2010 Study has been to systematically produce comparable estimates of the burden of 291 diseases and injuries and their associated 1,160 sequelae from 1990 to 2010 (Murray *et al.*, 2012a; Murray *et al.*, 2012b). We aimed to report here internally consistent

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prevalence and incidence estimates of severe tooth loss for all countries, 20 age groups, and both sexes for 1990 and 2010.

Materials & Methods

Detailed methods for each component of the GBD 2010 Study are described elsewhere (Murray *et al.*, 2012a). We provide a description here with emphasis on severe tooth loss.

Search Strategy for Identification of Studies

A systematic literature review was conducted at the Institute of Dentistry, Queen Mary University of London, between 2007 and 2011, following the *Cochrane Handbook* (Higgins and Green, 2011). The case definition of severe tooth loss was “having fewer than 9 remaining permanent teeth.” By default, this definition included those with severe tooth loss (*i.e.*, 1-9 teeth) as well as those with total tooth loss. There is evidence showing that having fewer than 10 teeth significantly affects diet, leading to either malnutrition or obesity (Sheiham *et al.*, 2001; Nowjack-Raymer and Sheiham, 2007). We sought to identify all studies presenting descriptive epidemiology data on total number of missing teeth and/or total tooth loss (*e.g.*, prevalence, incidence, remission, duration, case fatality, and cause-specific mortality) between January 1980 and December 2010 regardless of language, geography, age, sex, or publication status (Marcenes *et al.*, 2013).

Electronic searches were carried out in MEDLINE via PubMed, EMBASE via OVID, and LILACS via BIREME. In MEDLINE, we performed keyword- and MeSH-based searches. The MeSH terms were “mouth, edentulous/epidemiology” and “tooth loss/epidemiology,” and the keywords were edent*, “tooth loss,” “missing teeth,” “missing tooth,” “extracted teeth,” “extracted tooth,” toothless*, “teeth lost,” “lost teeth,” “tooth retention,” and “losing teeth.” The EMBASE search strategy included the subject heading “edentulousness/epidemiology” and the keywords “tooth loss,” “missing teeth,” “extracted

teeth,” “missing tooth,” “edentate,” and “edentulous.” The LILACS search strategy included the keywords “tooth loss,” “edentate,” “edentulous,” “missing teeth,” “extracted teeth,” “missing tooth,” and “extracted tooth.” We supplemented our electronic search with hand searches of reference lists of all relevant publications, textbooks, webpages of government health departments, and international health organizations. We wrote to chief dental officers worldwide requesting any conference reports, theses, government reports, and unpublished survey data.

Selection of Studies

Two trained reviewers (M.D. and B.B.) performed independent searches, assessed publication validity, and extracted the data in duplicate. Differences were resolved by discussion, rereading, and consultation with the senior member of the research team (W.M.) when necessary. Records of all references were combined in EndNote X4 (Thomas Reuters, Philadelphia, PA, USA).

Those studies found to be relevant after title and abstract screening were kept in the database. Articles addressing unrelated topics were excluded at this stage—such as genetics, laboratory diagnostic tests, experimental laboratory animal studies, letters to editors, case reports, case series reports, and other patient-based studies (*e.g.*, hospital-based studies). Studies rejected at this or subsequent stages were recorded in a table of excluded studies, and reasons for exclusion were noted.

The full text of all topic-related studies was assessed for methodological quality using a scale similar to the one devised by Loney *et al.* (1998). We did not, however, use a scoring system, owing to concerns over the validity of this procedure in general when assessing study quality (Juni *et al.*, 1999). All studies meeting the quality criteria for inclusion in this review were used in the meta-analysis. The quality criteria used in this review were observational longitudinal or cross-sectional studies (1) based on random samples; (2) representing national, subnational, or community populations; (3) measuring

severe tooth loss as defined for the GBD 2010 Study through clinical examination; (4) with a response rate higher than 50% for prevalence surveys and an attrition rate lower than 50% for longitudinal studies; and (5) reporting prevalence, incidence, or relative risk estimates or sufficient data for their calculation.

Data Extraction and Cleaning

Multiple data fields were extracted from each study according to GBD standards: condition name, case definition, country, region, date of study, parameter (*e.g.*, prevalence, incidence, duration, remission, case fatality and mortality), parameter value, units (per 100, 100,000, *etc.*), lower confidence interval value, upper confidence interval value, type of confidence interval, standard error, sample size, sex, and age range of participants. We also recorded multiple additional fields, including the data extractor's name, citation identifier, year of publication, coverage of study (*e.g.*, community, national, subnational), urban *vs.* rural, subject source (*e.g.*, schools, households), method of sampling (*e.g.*, convenience, random, systematic), response rates, reliability test used (Kappa, others), and reliability test values (intra- and interexaminer).

We made only limited modifications to data points. We distributed the total among the groups according to year- and country-specific age distributions when overall sample sizes were reported but not for each age group. If sample size was missing, we assigned it to be 100 (community studies), 250 (subnational studies), or 1,000 (national studies). If no exact age ranges were presented, descriptors such as “grade 5 elementary students” were extrapolated to assign appropriate age ranges. If no data collection date was presented, we assigned it to be 2 yr before publication. Countries were grouped in 21 regions and 7 super regions by geographic proximity and mean age of death, reflecting both population age structure and age-specific death rates—a simple summary measure of the demographic and epidemiologic transition (Murray *et al.*, 2012b; Wang *et al.*, 2012).

Data Handling and Modeling

The severe tooth loss database was modeled on DisMod-MR, a Bayesian metaregression tool developed for the GBD 2010 Study (Flaxman *et al.*, 2012). The generalized negative binomial metaregression model of DisMod-MR combines an age-integrating compartmental model of disease with covariates that predict variation in true rates; covariates that predict variation across studies due to measurement bias; fixed effects on sex; and random intercepts on super region, region, and country. The natural history of any disease can be described by a number of variables: incidence, prevalence, remission, duration, case fatality, and cause-specific mortality. DisMod-MR uses data on at least 3 of the above variables to generate any other estimate when the data are sparse. For example, if prevalence is unknown but incidence, case fatality, and remission are, then prevalence can be calculated via a compartmental model (Institute for Health Metrics and Evaluation, 2009). For countries with sparse or nondata, the prediction of true rates was facilitated by defaulting to the average of a similar area and taking advantage of relations with covariates in the metaregression. The estimation equations and approach to numerical solutions, with examples, have been reported elsewhere (Murray *et al.*, 2012a).

A number of disease-specific limits were imposed to reflect the known epidemiology of tooth loss. As would be expected for an irreversible condition, remission was fixed at zero throughout life. Mortality and relative risk were both fixed at zero before age 30 yr, as any excess cardiovascular events associated with severe tooth loss would not be expected at younger ages. We also assigned incidence and prevalence to be zero at younger ages (*i.e.*, from 0 to 15 yr for incidence and from 0 to 20 yr for prevalence). The age cutoffs when incidence and prevalence were allowed to rise (15 and 20 yr, respectively) were based on the age at which the permanent dentition is expected to have fully formed in all individuals.

Figure 1.

Flowchart of the selection of studies for the review.

Prevalence estimates from the primary literature review showed severe tooth loss declining across several regions during the most recent years. We compared estimates with and without year effects. Without the year covariate, the DisMod-MR estimates did not appropriately approximate the changes over time. A covariate for year was therefore added to the prediction model, capturing time trends in prevalence observed in the database. The year covariate also allowed estimates in those regions with sparse data to reflect improved prevalence of severe tooth loss over time.

To capture uncertainty in all estimates, we ran 1,000 different Monte Carlo simulations of 20,000 individuals for each age, sex, country, and year. Aggregations were made at the level of the 1,000 draws for all estimates. The uncertainty interval (UI) around each quantity of interest is presented as the 2.5th and 97.5th centiles, which can be interpreted as a 95% UI. As such, they are meant to convey the strength of the evidence for any age, sex, country, or year group.

Results

A flowchart describing the systematic review search results is presented in Figure 1. The search yielded 5,618 unique citations. After titles and abstracts were screened, 5,285 citations were excluded as clearly not relevant to this systematic review, leaving 333 for full-text review; 265 publications were further excluded following the validity assessment. All data were drawn from published studies. Nearly all reports identified from searches of the gray literature were publications already included in our database. The main source of gray literature was World Health Organization regional databases, which included mainly published data. Experts and chief dental officers worldwide confirmed lack of data or informed that their data were published.

Quality of Reviewed Studies

The major quality flaws identified were related to adopting nonclinical outcome measures ($n = 128$) and inadequate population samples ($n = 125$). The latter included studies adopting

non-population-based, convenience, or nonrandom samples or were carried out with patients, volunteers, institutionalized groups (*i.e.*, prisoners, nursing homes), occupational groups (*i.e.*, army recruits, unemployed), or specific groups (*i.e.*, ethnic minority, immigrants, members of an association, high-risk groups). Twelve secondary data analysis studies were also excluded after the full text was read (Figure 1).

Included Studies

A total of 68 studies were included in the quantitative synthesis, including 285,746 individuals aged 12 yr or older in 26 countries (covering 12 and 6 of the 21 regions and 7 super regions of the GBD, respectively). The full list of included studies is presented in Appendix Table 1. The Table presents the characteristics of the included studies by world region. The majority of studies were prevalence surveys and were drawn from national or subnational reports (47 studies each). Furthermore, most studies were published in scientific journals (64 studies), increasing each decade (8 in 1980-1990, 24 in 1991-2000, and 36 in 2001-2010). Only 3 studies reported estimates for severe tooth loss.

In sum, 322 data points were extracted from the 68 studies, covering both sexes and 12 unique world regions and ranging in age from 12 to 99 yr. Three types of outcome measures were identified—namely, prevalence ($n = 293$), incidence ($n = 18$), and mortality ($n = 11$) related to severe tooth loss. Moreover, 81% of data points were from populations aged 30 yr or more, 48% for those more than 50 yr of age.

Prevalence and Incidence of Severe Tooth Loss

In 2010, 2.3% of the global population, representing 158 million people worldwide, was edentate (95% UI: 2.1%, 2.5%). Between 1990 and 2010, the global age-standardized prevalence of severe tooth loss in the entire population decreased from 4.4% (95% UI: 4.1%, 4.8%) to 2.4% (95% UI: 2.2%, 2.7%), a 45% decrease. The global age-standardized incidence rate of severe

tooth loss in 2010 was 205 cases per 100,000 person-years (95% UI: 187, 226), a significant 45% decrease from the 1990 incidence rate of 374 cases per 100,000 person-years (95% UI: 347, 406). Women generally showed higher age-standardized prevalence and incidence of severe tooth loss than men, although the gap between sexes has reduced over time with only minor differences seen in 2010. In both sexes, prevalence increased gradually with age, showing a steep increase around the seventh decade of life that was associated with a peak in incidence at 65 yr (Figure 2). These age patterns have not changed during the past 2 decades in spite of the gradual declines in prevalence and incidence within the same period.

Geographic differences in severe tooth loss prevalence are readily apparent. Age-standardized prevalence and incidence of severe tooth loss in 1990 and 2010 are reported by country and region in Appendix Table 2. All-ages prevalence (excluding nonsusceptible population < 20 yr old) is displayed in Figure 3. The corresponding breakdown of 1990 and 2010 prevalence estimates by sex, age groups, and GBD regions is reported in Appendix Table 3. The age-standardized prevalence of severe tooth loss in 2010 varied by country, from 1.5% (95% UI: 1.4%, 1.5%) in China to 3.9% (95% UI: 3.7%, 4.2%) in Brazil. While Brazil, Turkey, Iran, Mexico, and New Zealand were the countries where the prevalence of severe tooth loss was significantly higher than the global mean, China, Japan, Nigeria, Sri Lanka, and Sweden were those where the age-standardized prevalence of severe tooth loss was significantly below the global mean. Twenty-five countries showed significant decreases in the prevalence of total tooth loss between 1990 and 2010 (Appendix Table 2), with the largest drops observed in Slovenia, United Arab Emirates, Kuwait, Colombia, and Palestine (57% each).

All-ages incidence rate (in the susceptible population) is shown in Figure 4. The corresponding breakdown of 1990 and 2010 incidence estimates by sex, age groups, and GBD regions is reported in Appendix Table 3. The age-

standardized incidence rate of tooth loss varied by country from 137 new cases per 100,000 person-years in China (95% UI: 130, 144) to 339 per 100,000 person-years (95% UI: 211, 512) in Paraguay in 2010 as listed in Appendix Table 2. No countries had an age-standardized incidence rate statistically above the global mean, and only China was found to have an incidence rate that was statistically below the global mean. Furthermore, 24 countries showed significant decreases in the incidence rate of severe tooth loss between 1990 and 2010 (Appendix Table 2), with the largest declines observed in United Arab Emirates (61%) and Nicaragua and Panama (60% each).

Discussion

This review showed a significant reduction in the global burden of severe tooth loss between 1990 and 2010. Both the global age-standardized prevalence and incidence rate of total tooth loss in the entire population decreased by 45% over the last 2 decades—prevalence from 4.4% (95% UI: 4.1%, 4.8%) to 2.4% (95% UI: 2.2%, 2.7%) and incidence from 374 cases (95% UI: 347, 406) to 205 cases per 100,000 person-years (95% UI: 187, 226). These decreases are even starker when we examine only the susceptible populations (excluding those < 20 yr old), highlighting that even as most populations around the world live longer and have aged, the rates of severe tooth loss have dropped.

Sex differences have narrowed over the past 20 yr and were not significant in 2010. This may be related to a number of factors, including societal and cultural changes, improvement in female education, increased focus on women's health, and potentially even improved nutrition. Given the cumulative effects of oral diseases and, in consequence, tooth loss, both the prevalence and the incidence were age dependent. Prevalence increased exponentially with age, with incidence peaking around 60 yr. Similar profiles were seen in 1990 and 2010 despite declines in prevalence and incidence estimates over time. The low use of dental services

Table.

Characteristics of the Studies Included in the Review by Region

Type of Study	Type of Report	Country	Publication Year	Coverage	Outcome
Asia, East					
Prevalence: 5	Scientific paper: 6	China: 5	1980-1990: 1	National: 1	STL: 0
Incidence: 1	Survey report: 0	Hong Kong: 1	1991-2000: 3	Subnational: 3	TTL: 4
Mortality: 0			2001-2010: 2	Community: 2	
Asia, Southeast					
Prevalence: 1	Scientific paper: 1	Sri Lanka: 1	1980-1990: 0	National: 0	STL: 1 ^a
Incidence: 0	Survey report: 0		1991-2000: 0	Subnational: 1	TTL: 0
Mortality: 0			2001-2010: 1	Community: 0	
Asia Pacific, High Income					
Prevalence: 3	Scientific paper: 4	Japan: 4	1980-1990: 0	National: 1	STL: 0
Incidence: 0	Survey report: 0		1991-2000: 1	Subnational: 2	TTL: 4
Mortality: 1			2001-2010: 3	Community: 1	
Australasia					
Prevalence: 7	Scientific paper: 6	Australia: 3	1980-1990: 1	National: 5	STL: 0
Incidence: 1	Survey report: 2	New Zealand: 5	1991-2000: 2	Subnational: 2	TTL: 8
Mortality: 0			2001-2010: 5	Community: 1	
Europe, Central					
Prevalence: 1	Scientific paper: 1	Hungary: 1	1980-1990: 0	National: 1	STL: 0
Incidence: 0	Survey report: 0		1991-2000: 0	Subnational: 0	TTL: 1
Mortality: 0			2001-2010: 1	Community: 0	
Europe, Western^b					
Prevalence: 17	Scientific paper: 23	Denmark: 2	1980-1990: 2	National: 7	STL: 1 ^a
Incidence: 4	Survey report: 2	Germany: 1	1991-2000: 10	Subnational: 9	TTL: 24
Mortality: 4		Spain: 2	2001-2010: 13	Community: 9	
Latin America, Central					
Prevalence: 1	Scientific paper: 1	Mexico: 1	1980-1990: 0	National: 1	STL: 0
Incidence: 0	Survey report: 0		1991-2000: 0	Subnational: 0	TTL: 1
Mortality: 0			2001-2010: 1	Community: 0	
Latin America, Tropical					
Prevalence: 4	Scientific paper: 4	Brazil: 4	1980-1990: 0	National: 0	STL: 0
Incidence: 0	Survey report: 0		1991-2000: 0	Subnational: 2	TTL: 4
Mortality: 0			2001-2010: 4	Community: 2	
North Africa / Middle East					
Prevalence: 2	Scientific paper: 2	Iran: 1	1980-1990: 0	National: 2	STL: 1 ^a
Incidence: 0	Survey report: 0	Turkey: 1	1991-2000: 0	Subnational: 0	TTL: 1
Mortality: 0			2001-2010: 2	Community: 0	
North America, High Income					
Prevalence: 4	Scientific paper: 14	Canada: 2	1980-1990: 4	National: 6	STL: 0
Incidence: 7	Survey report: 0	US: 12	1991-2000: 8	Subnational: 2	TTL: 14
Mortality: 3			2001-2010: 2	Community: 6	

(continued)

Table.
(continued)

Type of Study	Type of Report	Country	Publication Year	Coverage	Outcome
Sub-Saharan Africa, Southern					
Prevalence: 1	Scientific paper: 1	South Africa: 1	1980-1990: 0	National: 1	STL: 0
Incidence: 0	Survey report: 0		1991-2000: 0	Subnational: 0	TTL: 1
Mortality: 0			2001-2010: 1	Community: 0	
Sub-Saharan Africa, West					
Prevalence: 1	Scientific paper: 1	Nigeria: 1	1980-1990: 0	National: 0	STL: 0
Incidence: 0	Survey report: 0		1991-2000: 0	Subnational: 1	TTL: 1
Mortality: 0			2001-2010: 1	Community: 0	

STL, severe tooth loss; TTL, total tooth loss.

^aOnly 3 studies reported estimates for STL. As they also reported estimates for TTL, the latter set of estimates was extracted for the quantitative synthesis.

^bFinland: 2; France: 2; UK: 2; Ireland: 1; Italy: 1; Netherlands: 1; Norway: 2; Sweden: 9.

Figure 2.

Prevalence (proportion) and number of incident cases of severe tooth loss in 1990 (light line) and 2010 (dark line) with 95% uncertainty intervals by age.

even in developed countries, the lack of financial support from government and/or third-party payment systems, and the absence of relevant oral health policies are some of the key issues that may explain elderly's poorer oral health status (Petersen *et al.*, 2010). It is possible that patients' as well as dentists' treatment preferences and expectations of dental services change around this period of life in line with social theories of aging, by which withdrawal from social roles (disengagement) and lack of social policies to protect senior adults (structured dependency) may affect their health (Bartley *et al.*, 1997; Higgs, 2008).

Significant geographic differences were observed. Previous data showed conflicting results, and it has been claimed that oral health is deteriorating in developing countries (World Health Organization, 2003; Petersen *et al.*, 2005). Our data also clarify that oral health assessed by prevalence and incidence of severe tooth loss is improving in most places: developing and developed countries with significant reductions in most of the 21 GBD world regions. However, similar improvements have not yet been achieved in South Asia, Eastern Europe, Southern Latin America, Oceania, and Central Sub-Saharan Africa.

Some methodological issues need to be mentioned. First, the quality of a systematic review depends on the quality of the primary studies included in it. As was true for all GBD 2010 causes, we sought to identify all relevant and high-quality data sources for severe tooth loss regardless of language or publication status, but because of time and resource constraints, there may be sources in some locations that were missed. Language, publication, and citation biases are common in systematic reviews. However, our findings compared favorably with most country-level measurements of tooth loss prevalence at the population level

Figure 3.

Age-standardized prevalence (proportion) of severe tooth loss in 2010 worldwide.

(Mojon *et al.*, 2004; Hugoson *et al.*, 2005; Dye *et al.*, 2007; Müller *et al.*, 2007; Steele *et al.*, 2012), which is not surprising given that our models used all such data as inputs. A second challenge was inherent to the reporting of tooth loss. The present findings may be interpreted as prevalence and incidence of total tooth loss in the total population, rather than severe tooth loss (< 10 teeth). The majority of studies reported only estimates for total tooth loss; therefore, estimates of severe and total tooth loss are virtually the same. We encourage researchers in public health dentistry to assess and report both the total number of teeth per person in the entire population and the proportion of the edentate population. In lieu of the present findings, an additional useful outcome could be the proportion of people with functional dentition (*i.e.*, having > 20 teeth). A third challenge was the sparse data and/or the quality of published and unpublished data in certain regions of the globe. Nine regions had not contributed any data; data were scarce in

younger age groups; and there was little to directly inform incidence and mortality estimates. We used a DisMod-MR facility to infer data from a similar geographic area to those without data, adjusting estimates by covariates in metaregression modeling (Murray *et al.*, 2012a). All figures were estimated with a measure of uncertainty. The width of 95% UIs thus provides a mechanism of communicating the limitations of estimates.

This pooled analysis provided the most comprehensive epidemiologic data on severe tooth loss to date, and our figures provide a unique perspective in shaping public health policy. The evidence presented shows how important the understanding of the epidemiology of severe tooth loss and its consequences are for treatment planning and decision making in clinical dentistry as well as for needs assessment and planning services in public health. The data also have implications for the content of the dental curriculum in schools around the world, as advocated by others (Douglass

et al., 2002; Mojon *et al.*, 2004). The data provide governments and national and international nongovernmental agencies the evidence-based data to determine priorities for research, educational curriculum development, policies, and funding (Murray and Lopez, 1996; Murray *et al.*, 2012b; Murray *et al.*, 2013).

Although the reasons for decreased severe tooth loss burden may be multifactorial, it is tempting to speculate that coordinated efforts in treating dental diseases and preventing tooth loss throughout life may have had a significant positive impact on reducing severe tooth loss, the ultimate oral health disposition of populations. The main causes of tooth loss are untreated caries and periodontal diseases. Once oral disease occurs, treatment is the major approach to stop its progress, and lack of treatment is likely to lead to tooth loss. The reduction in levels of severe tooth loss experienced in the past 2 decades, together with nonsignificant changes in the global age-standardized prevalence and incidence of

Figure 4.

Age-standardized incidence (per 100,000 person-years) of severe tooth loss in 2010 worldwide.

severe chronic periodontitis and untreated dental caries (data not shown, reports in preparation), suggests that dental health services have been effective in preventing the consequences of the main 2 oral diseases. Ironically, prevention of tooth loss may explain nonsignificant concurrent increases in prevalence and incidence of severe chronic periodontitis and untreated dental caries.

In conclusion, our systematic review and meta-analysis of available quality literature on the epidemiology of severe tooth loss shows a significant decline in the prevalence and incidence of total tooth loss between 1990 and 2010 at the global, regional, and country levels.

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References

- Baelum V, van Palenstein Helderma W, Hugoson A, Yee R, Fejerskov O (2007). A global perspective on changes in the burden of caries and periodontitis: implications for dentistry. *J Oral Rehabil* 34:872-906.
- Bartley M, Blane D, Montgomery S (1997). Health and the life course: why safety nets matter. *BMJ* 314:1194-1196.
- Douglass CW, Shih A, Ostry L (2002). Will there be a need for complete dentures in the United States in 2020? *J Prosthet Dent* 87:5-8.
- Dye BA, Tan S, Smith V, Lewis BG, Barker LK, Thornton-Evans G, *et al.* (2007). Trends in oral health status: United States, 1988-1994 and 1999-2004. *Vital Health Stat* 348:1-92.
- Fejerskov O, Escobar G, Jossing M, Baelum V (2013). A functional natural dentition for all—and for life? The oral healthcare system needs revision. *J Oral Rehabil* 40:707-722.
- Flaxman AD, Vos T, Murray CJ (2012). *The meta-regression of descriptive epidemiology model*. Seattle, WA: University of Washington Press.
- Higgins JPT, Green S, eds. (2011). *Cochrane handbook for systematic reviews of interventions*, Version 5.1.0 [updated March 2011]. Oxford: Cochrane Collaboration. URL accessed on 5/9/2014 at: <http://www.cochrane-handbook.org>.
- Higgs P (2008). Later life, health and society. In: *Sociology as applied to medicine*; Scambler G, editor. London, UK: Elsevier, pp. 176-192.
- Hugoson A, Koch G, Gothberg C, Helkimo AN, Lundin SA, Norderyd O, *et al.* (2005). Oral health of individuals aged 3-80 years in Jonkoping, Sweden during 30 years (1973-2003): II. Review of clinical and radiographic findings. *Swed Dent J* 29:139-155.
- Institute for Health Metrics and Evaluation (2009). *Operation manual: Final draft*. Seattle, WA: University of Washington.
- Juni P, Witschi A, Bloch R, Egger M (1999). The hazards of scoring the quality of clinical trials for meta-analysis. *JAMA* 282:1054-1060.
- Loney PL, Chambers LW, Bennett KJ, Roberts JG, Stratford PW (1998). Critical appraisal of the health research literature: prevalence or incidence of a health problem. *Chronic Dis Can* 19:170-176.
- Marcesen W, Kassebaum NJ, Bernabe E, Flaxman A, Naghavi M, Lopez A, *et al.* (2013). Global burden of oral conditions in

- 1990-2010: a systematic analysis. *J Dent Res* 92:592-597.
- Mojon P, Thomason JM, Walls AW (2004). The impact of falling rates of edentulism. *Int J Prosthodont* 17:434-440.
- Müller F, Naharro M, Carlsson GE (2007). What are the prevalence and incidence of tooth loss in the adult and elderly population in Europe? *Clin Oral Implants Res* 18(suppl 3):2-14.
- Murray CJ, Lopez AD (1996). Evidence-based health policy: lessons from the Global Burden of Disease Study. *Science* 274:740-743.
- Murray CJ, Ezzati M, Flaxman AD, Lim S, Lozano R, Michaud C, *et al.* (2012a). GBD 2010: design, definitions, and metrics. *Lancet* 380:2063-2066.
- Murray CJ, Vos T, Lozano R, Naghavi M, Flaxman AD, Michaud C, *et al.* (2012b). Disability-adjusted life years (DALYs) for 291 diseases and injuries in 21 regions, 1990-2010: a systematic analysis for the Global Burden of Disease Study 2010. *Lancet* 380:2197-2223.
- Murray CJ, Richards MA, Newton JN, Fenton KA, Anderson HR, Atkinson C, *et al.* (2013). UK health performance: findings of the Global Burden of Disease Study 2010. *Lancet* 381:997-1020.
- Nowjack-Raymer RE, Sheiham A (2007). Numbers of natural teeth, diet, and nutritional status in US adults. *J Dent Res* 86:1171-1175.
- Petersen PE, Bourgeois D, Ogawa H, Estupinan-Day S, Ndiaye C (2005). The global burden of oral diseases and risks to oral health. *Bull World Health Organ* 83:661-669.
- Petersen PE, Kandelman D, Arpin S, Ogawa H (2010). Global oral health of older people: call for public health action. *Community Dent Health* 27(4)(suppl 2):257-267.
- Sheiham A, Steele JG, Marcenes W, Lowe C, Finch S, Bates CJ, *et al.* (2001). The relationship among dental status, nutrient intake, and nutritional status in older people. *J Dent Res* 80:408-413.
- Steele JG, Treasure ET, O'Sullivan I, Morris J, Murray JJ (2012). Adult Dental Health Survey 2009: transformations in British oral health 1968-2009. *Br Dent J* 213:523-527.
- Wang H, Dwyer-Lindgren L, Lofgren KT, Rajaratnam JK, Marcus JR, Levin-Rector A, *et al.* (2012). Age-specific and sex-specific mortality in 187 countries, 1970-2010: a systematic analysis for the Global Burden of Disease Study 2010. *Lancet* 380:2071-2094.
- World Health Organization (2003). *The world oral health report 2003: continuous improvement of oral health in the 21st century. The approach of the WHO Global Oral Health Programme*. Geneva, Switzerland: World Health Organization.