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Global Burden of Untreated Caries: A Systematic Review and Metaregression

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Abstract

We aimed to consolidate all epidemiologic data about untreated caries and subsequently generate internally consistent prevalence and incidence estimates for all countries, 20 age groups, and both sexes for 1990 and 2010. The systematic search of the literature yielded 18,311 unique citations. After screening titles and abstracts, we excluded 10,461 citations as clearly irrelevant to this systematic review, leaving 1,682 for full-text review. Furthermore, 1,373 publications were excluded following the validity assessment. Overall, 192 studies of 1,502,260 children aged 1 to 14 y in 74 countries and 186 studies of 3,265,546 individuals aged 5 y or older in 67 countries were included in separate metaregressions for untreated caries in deciduous and permanent teeth, respectively, using modeling resources from the Global Burden of Disease 2010 study. In 2010, untreated caries in permanent teeth was the most prevalent condition worldwide, affecting 2.4 billion people, and untreated caries in deciduous teeth was the 10th-most prevalent condition, affecting 621 million children worldwide. The global age-standardized prevalence and incidence of untreated caries remained static between 1990 and 2010. There is evidence that the burden of untreated caries is shifting from children to adults, with 3 peaks in prevalence at ages 6, 25, and 70 y. Also, there were considerable variations in prevalence and incidence between regions and countries. Policy makers need to be aware of a predictable increasing burden of untreated caries due to population growth and longevity and a significant decrease in the prevalence of total tooth loss throughout the world from 1990 to 2010.

Keywords: global health, decay, root caries, prevalence, incidence, epidemiology

Introduction

Dental caries manifests as a continuum of disease states of increasing severity and tooth destruction, ranging from subclinical changes to lesions with dentinal involvement (Featherstone 2004; Kidd and Fejerskov 2004). The initial stages of caries are asymptomatic, with symptoms starting after the carious lesion has progressed into dentine (Selwitz et al. 2007). The current standard for caries detection in epidemiologic surveys in most countries is the World Health Organization (WHO; 1997, 2013) criteria, which measure caries at cavitation level.

Common caries indices measure past and present disease experience. Caries experience reflects lifetime prevalence and, though important to understand the natural history of the disease, gives no information on levels of current active disease, which is arguably more important for the assessment of disease burden and planning dental care services. Current methods to assess disease burden are based on disability (Kassebaum et al. 2014a). The rational is the assumption that treated diseases do not cause burden and that past caries experience (DMFT) reflects both treated and untreated caries. Despite this important distinction, to date most reviews on caries epidemiology have focused only on caries experience (WHO 2003; Marthaler 2004; Thomson 2004; Griffin et al. 2005; Bagramian et al. 2009). Although it is accepted that lifetime prevalence of dental caries experience measured by the DMF index has declined in the last 40 y in many developed countries (Marthaler 2004; Bernabé and Sheiham 2014) and that individuals are susceptible to caries throughout life (Thomson 2004; Griffin et al. 2005; Broadbent et al. 2013), the epidemiology of untreated caries is not yet fully understood.

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. A key aspect of the GBD study was to enforce consistency between disease estimates of mortality and other epidemiologic parameters (prevalence,

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incidence, remission, and duration). The aim of this article was to report internally consistent prevalence and incidence estimates of untreated caries for 187 countries, 20 age groups, and both sexes for 1990 and 2010.

Materials and Methods

Detailed methods for each component of the GBD 2010 study are described elsewhere (Murray, Ezzati, et al. 2012). We focus here on untreated caries.

Search Strategy for Identification of Studies

A systematic literature review was conducted at the Department of Clinical and Diagnostic Oral Science, Institute of Dentistry, Queen Mary University of London, between 2007 and 2011, following the *Cochrane Handbook* (Higgins and Green 2011) for constructing the search strategy and identifying the studies. The GBD case definition of untreated caries was "teeth with unmistakable coronal cavity at dentine level, root cavity in cementum that feels soft or leathery to probing, temporary or permanent restorations with a caries lesion" (Harvard Initiative for Global Health et al. 2008; Marcenes et al. 2013). We sought to identify all studies presenting untreated caries–related descriptive epidemiology data between January 1, 1980, and December 31, 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 "dental caries/epidemiology," "dental caries/statistics and numerical data," and "tooth demineralization/epidemiology," and the keywords were "caries," "decay*," and "tooth demineralization."

The EMBASE search strategy included the subject heading "dental caries/epidemiology" and the keywords "dental caries and decay*." The LILACS search strategy included the keywords "dental caries," "decay*," and "tooth demineralization." 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 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).

Articles addressing unrelated topics were not kept in the database after title and abstract screening. The full text of all topic related studies was assessed. Articles reporting mean caries experience with no further information were excluded at this stage. Studies rejected at this or subsequent stages were recorded in a table of excluded studies, and reasons for exclusion were noted.

The remaining studies were 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 when assessing study quality (Juni et al. 1999). The quality criteria used in this review were observational longitudinal (regardless of study design, prospective or retrospective, or duration of follow-up) or cross-sectional studies (1) based on random samples; (2) representing national, subnational, or community populations; (3) measuring untreated caries as defined for the GBD 2010 study through clinical examination; and (4) with a response rate >50% for prevalence surveys and an attrition rate <50% for longitudinal studies.

Data Extraction and Cleaning

Multiple data fields were extracted from each study according to GBD standards. We made only limited modifications to data points. When overall sample sizes were reported but not for each age group, we distributed the total among the groups according to year- and country-specific age distributions. If sample size was missing entirely, we assigned it to be 100, 250, or 1,000 for community, subnational, and national studies, respectively (Harvard Initiative for Global Health et al. 2008; Kassebaum et al. 2014a, 2014b). 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 y prior to publication. In 2 cases, studies conducted in the former Yugoslavia were completed in what is now Slovenia and therefore reclassified as being from Slovenia. These assumptions have no influence on the results in sensitivity analysis. Countries were grouped in 21 regions and 7 superregions by geographic proximity and mean age of death, which reflects both population age structure and age-specific death rates—a simple summary measure of the demographic and epidemiological transition (Murray, Vos, et al. 2012; Wang et al. 2012).

The dental literature tends to report lifetime prevalence of caries experience, and the dmft and DMFT indexes are the universal measure used in surveys for caries experience in deciduous and permanent teeth, respectively. We extracted data from different scenarios: (1) studies reporting prevalence/incidence of untreated caries (d/D component of the dmft/DMFT), (2) studies reporting prevalence of caries experience and mean caries experience (or incidence of caries experience and mean caries increment) with information on component breakdown of dmf/DMFT scores, and (3) studies reporting prevalence of caries experience and mean caries experience with no further information. In the case of deciduous caries, where decay is the dominant portion or dmft, we cross-walked mean caries experience to prevalence of untreated caries using the d/dmf ratio from within the study (scenario 2) or, if not available, from the

country- or region-specific average d/dmf ratio (scenario 3). For permanent caries, the relation between untreated caries and D/DMF ratio is not consistent with respect to age and geography, so we included only articles reporting prevalence/incidence of untreated caries.

For studies that reported increment in dmft/DMFT but not incidence data, we extrapolated the latter from 2 types of studies. First, for longitudinal studies, the increment in dmft/DMFT between examinations was considered to be equivalent to the incidence of untreated caries over the study duration. Narrow age and time intervals were preferred; most were ≤3 y. If a study performed only a single cross-sectional examination but reported data in age intervals of 1 y, we extrapolated incidence data in a similar manner. We changed to 2-y age intervals only if the increment was zero or negative over a single 1-y interval. We did not extrapolate incidence data if the age or time interval was >10 y. We also did not use dmfs/DMFS data in this calculation the mapping from affected surfaces to affected teeth is inconsistent.

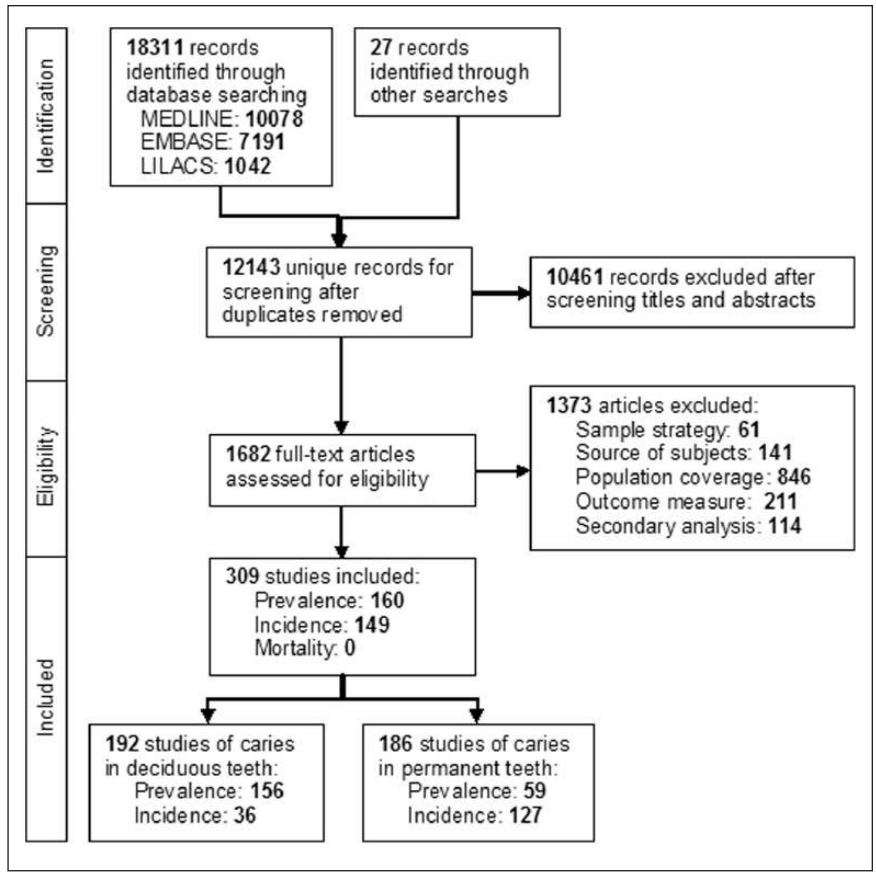

Figure 1. Flowchart of the selection of studies for the review.

Data Handling and Modeling

The untreated caries database was modeled using 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 nested random intercepts on superregion, 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 using a compartmental model (Harvard Initiative for Global Health et al. 2008). For countries with sparse data, the prediction of true rates was facilitated by defaulting to the average of a region, superregion, or the world 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, Ezzati, et al. 2012).

Two sources of systematic bias were present in the data. The first source of bias was related to different scenarios to report caries experience as described above. We accounted for this with the use of study-level covariates to facilitate cross-walking in DisMod-MR metaregressions. The second source of bias was due to the exclusion of edentate individuals from study populations. While this makes sense within the context of individual studies, it leads to systematic overestimation of prevalence when modeled over the entire population. To account for this, we adjusted the prevalence numbers estimated by DisMod-MR by subtracting the age-, sex-, and region-specific prevalence of edentulism from the denominator. For instance, if 40% of 70- to 74-y-old women were estimated to be edentate in a certain region, the corresponding estimates for untreated caries prevalence were reduced to 60% of the original value.

We modeled untreated caries in deciduous and permanent teeth separately. In both cases, we assigned excess mortality to be 0 and relative risk to be 1 from age 0 to 100 y, as serious health consequences of untreated caries were assumed to be uncommon and death very rare. For modeling untreated caries in deciduous teeth, we fixed incidence and prevalence at zero from age 14 y when exfoliation is presumed to be complete. This age was chosen because 13 y was the oldest age

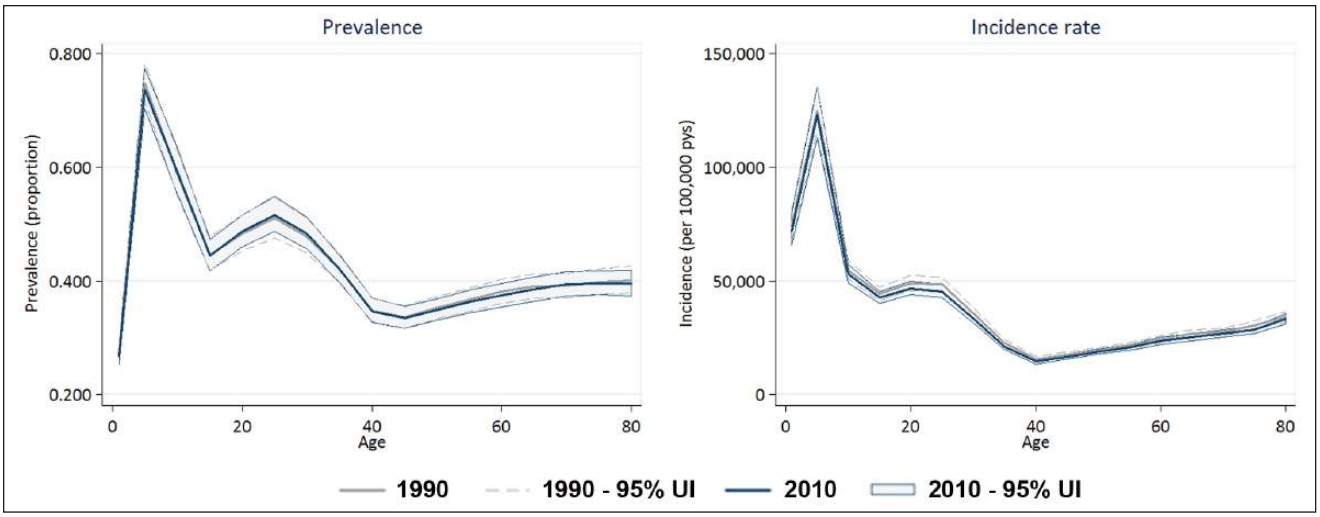

Figure 2. Prevalence (proportion) and number of incident cases of untreated caries in 1990 (light line) and 2010 (dark line) with 95% uncertainty intervals by age.

of a nonzero prevalence data point. We additionally assigned incidence and prevalence to be 0 before age 1 y to indicate that this condition never begins at birth and is relatively rare in the neonatal and postneonatal periods. Incidence bounds of 0 to 5 were chosen based on the highest-value datum in the data set. An upper remission bound of 10 was chosen because this would correspond to roughly 50% of children having complete resolution of their caries within 1 mo or >99% within 6 mo. As prevalence was assigned to be zero from age 14 y, we elected not to include a lower remission bound. We did not assign any specific bounds to duration because with strict age limits on prevalence and incidence, it was unnecessary. We used the linear spline to represent the age-specific rates with knots at ages 0, 1, 3, 5, 7, 9, 11, 13, and 14 y. No country-level covariates were included. We used 3 study-level covariates for prevalence data as described above. Study-level covariates indicated whether a given data point was the "true" prevalence of untreated caries or adjusted according to a dt/dmft correction factor or a regional population-weighted average dt/dmft correction factor.

For modeling untreated caries in permanent teeth, we allowed incidence and prevalence to rise from zero starting at age 5. Although caries in permanent teeth are rare until the age 6 y, the data set suggested that they are sometimes incident in 5-y-olds. Incidence bounds were again based on an examination of the data set and the addition of a margin to the highest reported value. In this case, incidence bounds were 0 and 3. Lower bounds for remission were set at 0.3, as this would represent only approximately 50% of untreated caries remitting in 3 y. The upper bound that we chose was 20, as this would be equivalent to >99% remission in 3 mo. We bounded duration to a maximum of 5 y for any individual episode of untreated caries. By this time, it is assumed that a decayed tooth would have been filled, extracted, or fallen out. We again used the linear spline to represent the age-specific rates with knots at ages 0, 5, 6, 10, 25, 40, 65, and 100 y. We did not use any country- or study-level covariates in this model, but we did add a prior to help address the substantial differences in data between regions. DisMod-MR iterates to find fully consistent incidence, prevalence, remission, and mortality at the empirical prior estimation step. With very heterogeneous data (such as this data set), finding such a solution can be difficult and predisposes to nonconvergence of the model. We therefore allowed the global priors to be inconsistent (i.e., not perfectly satisfy the compartmental model). Internal consistency for each region was still ensured at the posterior estimation stage.

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 18,311 unique citations. After screening titles and abstracts, we excluded 10,461 citations as clearly irrelevant to this review, leaving 1,682 for full-text review. Furthermore, 1,373 publications were excluded following the validity assessment. Nearly all reports identified from searches of the gray literature were publications already included in our database. The main source of gray literature (publications not controlled by commercial publishers; e.g., webpages) was WHO regional databases, which included mainly published data. Experts and chief dental officers worldwide confirmed lack of data or informed us that their data had been published. Only 27 reports were novel to us. Seven reports were acceptable after validity assessment.

Table 1. Age-standardized Prevalence and Incidence Rates and 95% Uncertainty Intervals of Untreated Dental Caries in Deciduous Teeth in 1990 and 2010 for Both Sexes Combined.

	Prevalence			
Region/Country	1990		2010	
Global	8.9	8.6–9.2	8.8	8.5–9.1
Asia Pacific, high income	10.8	9.8–11.8	9.6	8.6–10.7
Asia, Central	8.4	7.3–9.7	8.4	7.3–9.6
Asia, East	10.1	9.6–10.6	9.2	8.5–9.9
Asia, South	8.9	8.1–9.9	9.4	8.6–10.3
Asia, Southeast	9.8	9.0–10.6	10.4	9.6–11.2[a]
Australasia	5.8	5.1–6.6	4.9	4.3–5.5[b]
Caribbean	8.3	7.2–9.6	8.3	7.3–9.6
Europe, Central	9.1	8.4–9.9	8.9	8.2–9.7
Europe, Eastern	8.1	7.3–9.1	8	7.0–8.9
Europe, Western	6.5	6.1–6.9	6.5	6.0–7.0[b]
Latin America, Andean	8.4	7.1–9.9	8.3	7.0–9.8
Latin America, Central	7.5	6.7–8.2	7.1	6.4–7.9[b]
Latin America, Southern	7.8	7.1–8.6	7.9	7.0–8.7
Latin America, Tropical	9.4	8.7–10.1	9.1	8.4–9.8
North Africa / Middle East	8.4	7.7–9.3	9	8.3–9.8
North America, high income	9.2	8.3–10.1	9.2	8.3–10.1
Oceania	8	6.6–9.6	8.1	6.5–9.9
Sub-Saharan Africa, Central	7.7	6.2–9.3	7.7	6.3–9.2
Sub-Saharan Africa, East	7.8	7.1–8.5	7.9	7.2–8.8
Sub-Saharan Africa, Southern	6.8	6.2–7.4	7	6.2–7.8[b]
Sub-Saharan Africa, West	7.8	6.7–9.1	7.8	6.7–9.0
	Incidence			
Global	15,437	14,354–16,589	15,205	14,132–16,451
Asia Pacific, high income	18,282	16,028–21,162	15,848	13,502–18,858
Asia, Central	15,165	12,398–18,195	15,122	12,500–18,122
Asia, East	17,677	16,013–19,448	17,009	14,858–19,590
Asia, South	15,633	12,207–19,922	15,734	12,356–19,987
Asia, Southeast	18,567	15,516–21,870	19,895	16,820–23,315
Australasia	10,309	8,814–11,976	8,858	7,609–10,138[b]
Caribbean	14,250	11,825–17,194	14,465	11,768–17,669
Europe, Central	15,767	13,211–18,763	15,539	13,056–18,431
Europe, Eastern	13,886	11,893–16,203	13,857	11,808–16,256
Europe, Western	10,154	9,147–11,317	10,877	9,538–12,469[b]
Latin America, Andean	14,500	11,523–18,007	14,470	11,507–17,830
Latin America, Central	12,601	10,650–14,886	11,909	10,127–13,939[b]
Latin America, Southern	13,659	10,892–16,950	13,598	10,824–16,682
Latin America, Tropical	15,397	13,299–17,833	14,558	12,807–16,548
North Africa / Middle East	14,935	12,747–17,406	15,589	13,545–18,043
North America, high income	14,576	12,618–16,758	14,853	12,698–17,174
Oceania	15,459	11,925–19,698	15,578	12,137–19,806
Sub-Saharan Africa, Central	13,040	10,149–16,242	13,080	10,389–16,139
Sub-Saharan Africa, East	12,977	11,108–15,071	12,861	10,912–15,061
Sub-Saharan Africa, Southern	10,997	9,697–12,517	11,204	9,561–12,864[b]
Sub-Saharan Africa, West	12,872	10,702–15,471	12,952	10,605–15,795

Prevalence, per 100 population; incidence rate, per 100,000 person-years.
[a]Indicates a prevalence or incidence significantly higher than the global mean for 2010
[b]Indicates a prevalence or incidence significantly lower than the global mean for 2010.

Quality of Reviewed Studies

The major quality flaws identified related to outcome measure (n = 211) and/or source of subjects (n = 141). The latter included studies adopting non–population based, convenient, or nonrandom samples; those carried out with patients, volunteers, or institutional residents (e.g., prisoners, nursing homes); those conducted in occupational settings (e.g., army recruits, unemployed); or those focusing on specific groups (e.g., ethnic minority, immigrants, members of an association, high-risk groups). Also, 846 studies were considered unsuitable because of inadequate population coverage.

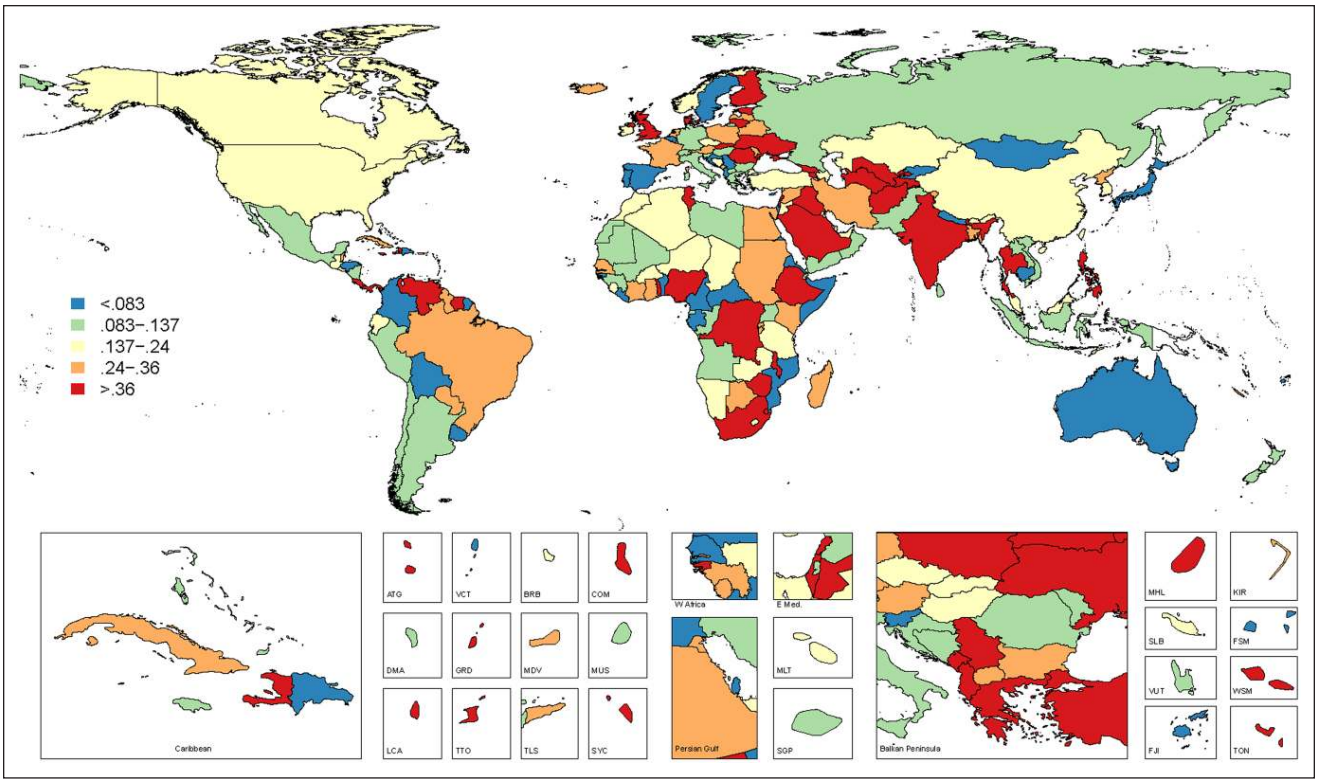

Figure 3. Age-standardized prevalence (proportion) of untreated caries in deciduous teeth in 2010: Worldwide.

Included Studies on Untreated Caries in Deciduous Teeth

A total of 192 studies were included in this analysis (Appendix Table 1), including 1,502,260 children aged 1 to 14 y in 74 countries (covering 18 of the 21 regions). Appendix Table 2 presents the characteristics of included studies by regions, with the largest numbers found in Western Europe, North Africa / Middle East, and East Asia. The majority of studies were prevalence surveys and were drawn from national or subnational reports. Furthermore, all studies were published in scientific journals, and there was an increase in numbers for each decade. From the 192 studies, 798 data points were extracted (prevalence, $n = 693$; incidence, $n = 105$).

Prevalence and Incidence of Untreated Caries in Deciduous Teeth

In 2010, untreated caries in deciduous teeth was the 10th-most prevalent condition, affecting 9% (95% UI: 8.7% to 9.4%) of the global population, or 621 million people worldwide. Between 1990 and 2010, the global age-standardized prevalence was static at 9% (95% UI: 8.6% to 9.2% in 1990; 8.5% to 9.1% in 2010). The age-standardized incidence was 15,205 cases per 100,000 person-years in 2010 (95% UI: 14,132 to 16,451), a nonsignificant decrease from the 1990 incidence of 15,437 cases per 100,000 person-years (95% UI: 14,354 to 16,589). Sex differences narrowed over the 20 y and were not significant in 2010. Prevalence reached its peak at age 6 y, with no appreciable change in such age pattern since 1990 (Fig. 2).

Geographic differences in 2010 age-standardized prevalence and incidence are shown in Table 1. All age prevalences (excluding nonsusceptible population) are displayed in Figure 3. The age-standardized prevalence varied by country, from 4.8% (95% UI: 4.2% to 5.4%) in Australia to 10.8% (95% UI: 9.8% to 11.7%) in the Philippines. The age-standardized incidence also varied significantly by country, from 8,835 cases per 100,000 person-years (95% UI: 7,626 to 10,103) in Australia to 19,914 cases per 100,000 person-years (95% UI: 17,181 to 22,973) in the Philippines (Appendix Table 3).

Included Studies on Untreated Caries in Permanent Teeth

A total of 186 studies were included in this analysis (Appendix Table 4), including 3,265,546 individuals aged 5 y or older in 67 countries (covering 18 of the 21 regions). Appendix Table 5 presents the characteristics of included studies by regions, with the largest numbers found in Western Europe, high-income North America, and Eastern sub-Saharan Africa. There were more incidence surveys than prevalence surveys, and most studies were drawn from national or subnational reports. Furthermore, most studies were published in scientific journals and equally each decade. From the 186 studies, 1,059 data points were extracted (prevalence, $n = 360$; incidence, $n = 699$).

Table 2. Age-standardized Prevalence and Incidence Rates and 95% Uncertainty Intervals of Untreated Dental Caries in Permanent Teeth in 1990 and 2010 for Both Sexes Combined.

	Prevalence			
Region/Country	1990		2010	
Global	35.5	33.7–37.6	35.4	33.7–37.3
Asia Pacific, high income	25.1	19.5–32.4	25.2	19.8–31.9[a]
Asia, Central	38.7	33.5–44.7	38.7	33.7–44.3
Asia, East	34.3	28.7–40.5	34.3	28.7–40.2
Asia, South	41.6	36.0–47.5	40.8	35.9–46.6
Asia, Southeast	34.6	30.7–39.4	35	30.9–39.7
Australasia	19.3	16.4–22.5	19.9	17.0–23.4[a]
Caribbean	35.5	30.1–41.2	35.9	30.6–42.1
Europe, Central	47.4	42.3–53.3	47.3	41.8–53.1[b]
Europe, Eastern	43.3	35.1–53.8	43.1	34.3–53.9
Europe, Western	35.3	32.5–38.6	35.8	33.1–39.0
Latin America, Andean	36.3	29.7–43.9	36.3	29.3–44.3
Latin America, Central	34.9	29.1–41.1	34.8	29.1–41.2
Latin America, Southern	44.7	38.1–52.8	44.9	38.1–52.4[b]
Latin America, Tropical	27.5	21.6–35.6	27.6	21.8–34.7
North Africa / Middle East	34.2	30.2–38.9	34.1	30.2–38.5
North America, high income	22.3	19.2–25.4	22	19.1–25.4[a]
Oceania	35.4	28.3–44.1	35.2	27.7–43.6
Sub-Saharan Africa, Central	36.3	29.2–45.1	36.4	29.2–45.5
Sub-Saharan Africa, East	32.9	29.4–36.8	32.8	29.6–36.3
Sub-Saharan Africa, Southern	37.1	32.9–41.9	36.9	32.6–41.7
Sub-Saharan Africa, West	31.1	28.5–34.2	31	28.2–33.7
	Incidence			
Global	28,689	27,069–30,381	27,257	25,808–28,928
Asia Pacific, high income	49,883	41,697–59,384	50,197	41,917–59,874[b]
Asia, Central	34,736	29,982–40,412	34,406	29,231–40,694
Asia, East	19,209	14,923–24,191	19,057	15,042–24,052[a]
Asia, South	16,229	13,119–19,946	16,293	13,079–19,917[a]
Asia, Southeast	28,952	24,259–34,644	28,848	24,344–34,263
Australasia	14,857	12,433–17,854	14,029	11,557–16,911[a]
Caribbean	27,704	23,084–32,666	27,199	22,994–32,431
Europe, Central	47,378	41,509–54,190	46,876	41,146–53,486[b]
Europe, Eastern	35,208	27,090–45,781	35,184	27,020–45,042
Europe, Western	50,741	46,755–54,816	49,344	45,036–53,912[b]
Latin America, Andean	47,406	38,624–58,757	47,568	38,857–58,365[b]
Latin America, Central	25,572	21,473–29,972	25,660	21,751–30,150
Latin America, Southern	35,524	27,175–45,745	35,533	27,168–45,433
Latin America, Tropical	48,751	38,385–61,029	48,151	37,790–59,975[b]
North Africa / Middle East	24,009	21,006–27,216	23,626	20,646–26,882
North America, high income	60,821	51,817–71,377	62,610	52,773–74,950[b]
Oceania	28,855	22,265–37,155	28,669	21,527–37,532
Sub-Saharan Africa, Central	27,426	21,270–35,498	27,742	21,109–35,911
Sub-Saharan Africa, East	27,813	24,544–31,702	27,959	24,441–31,790
Sub-Saharan Africa, Southern	29,380	22,735–37,822	28,975	22,290–37,110
Sub-Saharan Africa, West	16,044	14,233–18,039	16,249	14,358–18,166

Prevalence, per 100 population; incidence rate, per 100,000 person-years.
[a]Indicates a prevalence or incidence significantly lower than the global mean for 2010.
[b]Indicates a prevalence or incidence significantly higher than the global mean for 2010.

Prevalence and Incidence of Untreated Caries in Permanent Teeth

Untreated caries in permanent teeth was the most prevalent condition in 2010, affecting 35% (95% UI: 33.7% to 37.3%) of the global population, or 2.4 billion people worldwide. The global age-standardized prevalence remained static at 35% between 1990 and 2010 (1990, 95% UI: 33.7% to 37.6%; 2010, 95% UI: 33.7% to 37.3%). The age-standardized incidence was 27,257 cases per 100,000 person-years in 2010 (95% UI: 25,808 to 28,928). This estimate was comparable to the 1990 estimate of 28,689 cases per 100,000 person-years (95% UI: 27,069 to 30,381). Sex differences narrowed over the 20 y and were not significant in 2010. Prevalence reached its

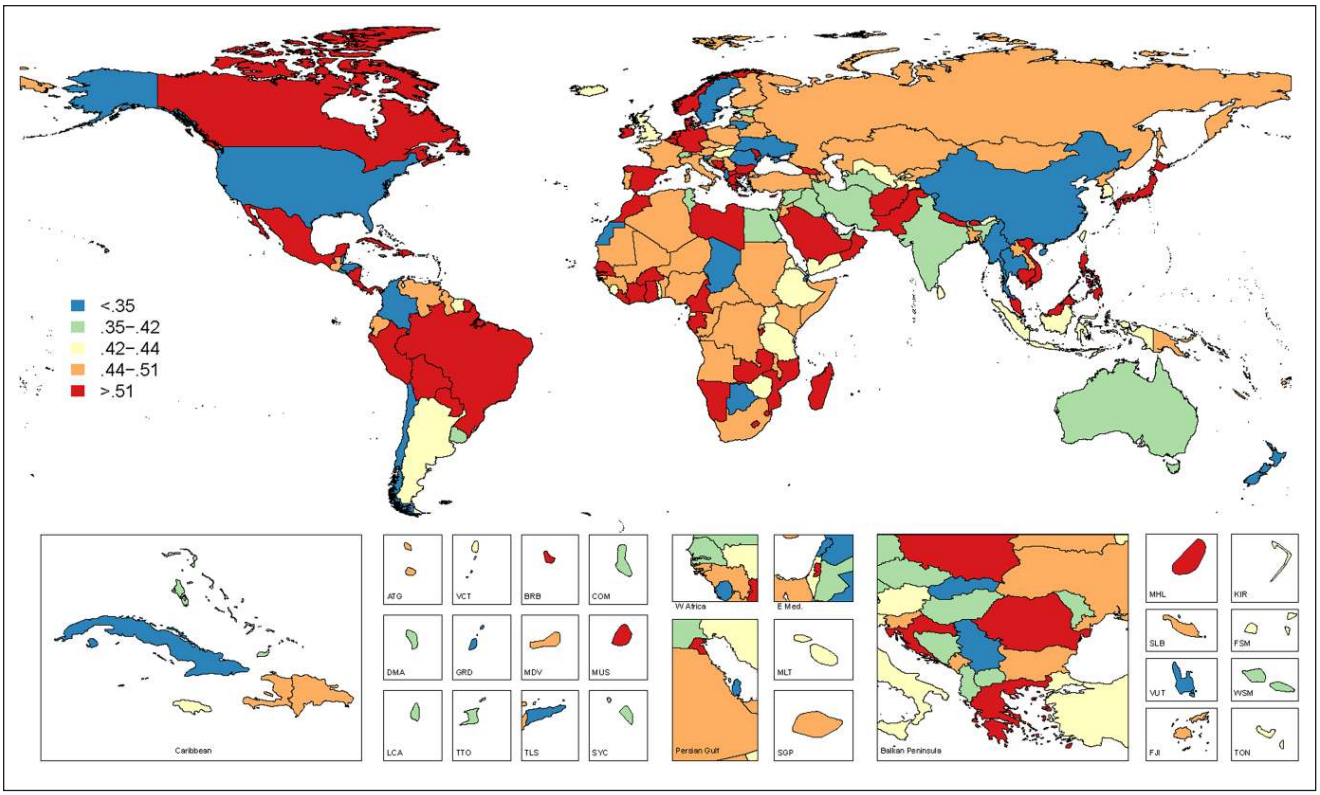

Figure 4. Age-standardized incidence (proportion) of untreated caries in permanent teeth in 2010: Worldwide.

peak at age 25 y, and there was a second peak later in life (around 70 y of age). This age pattern did not change appreciably since 1990 (Fig. 2).

Geographic differences in the 2010 age-standardized prevalence and incidence are shown in Table 2. All age prevalences (for the susceptible population) are displayed in Figure 4. The age-standardized prevalence varied by country, from 12% (95% UI: 9.9% to 14.9%) in Singapore to 68% (95% UI: 60.1% to 75.6%) in Lithuania. The age-standardized incidence also varied significantly by country, from 9,945 cases per 100,000 person-years (95% UI: 7,804-12,671) in Nigeria to 76,472 cases per 100,000 person-years (95% UI: 64,436-90,968) in Iceland (Appendix Table 6).

Discussion

Our findings have major implications for oral health policy and planning health services. Clearly, untreated caries pose a major public health challenge in most countries in the world. Untreated caries in permanent teeth was the most prevalent condition among all evaluated in the GBD 2010 study, affecting 2.4 billion people, and untreated caries in deciduous teeth was the 10th-most prevalent condition, affecting 621 million children worldwide. Our findings also indicate that 15 and 27 new cases of tooth decay in primary and permanent teeth, respectively, will develop annually from 100 people followed up.

Caries is the fourth-most expensive chronic disease to treat according to the WHO (Petersen 2008). In the United States alone, the projected spending for treatment of dental disease was $122 billion in 2014 (Centers for Medicare and Medicaid Services 2011). Furthermore, if left untreated, caries may cause severe pain and mouth infection (Selwitz et al. 2007), which affects children's school attendance and performance (Jackson et al. 2011) and adults' productivity at work (Petersen et al. 2005). Therefore, untreated caries represents a major biological, social, and financial burden on individuals and health care systems (Petersen et al. 2005). Policy makers need to be aware of a predictable further increase in untreated caries due to the growing world population that is associated with an increasing life expectancy and a massive decrease in the prevalence of tooth loss throughout the world from 1990 to 2010 (Kassebaum et al. 2014b).

We have also identified that the burden of untreated caries is shifting from children to adults. We hypothesized that the prevalence peak at age 25 y represents a delay in caries development, possibly due to promoting oral health to schoolchildren and then neglecting this aspect of health in adult life just after leaving school. Untreated caries is now peaking later in life, at adulthood rather than childhood. The current assumption—that the current low levels of caries in childhood will continue throughout the life course—may be incorrect. The worldwide dominant oral health promotion strategy is to focus efforts mainly on children aged 6 and 12 y, as reflected in the WHO (2003) international goals for improving oral health. Extending oral health promotion activities to the work environment and across the entire life span may help further improve oral health across the population. The third peak, in later life, is explained by the appearance of root caries.

Our data clarified that the prevalence and incidence of untreated caries remained unchanged in all regions of the

world over the 20 y studied. Previous data showed conflicting results, and it has been claimed that dental caries is decreasing in developed countries and increasing in developing countries, Africa in particular (WHO 2003; Petersen et al. 2005). Our data confirmed that the burden of untreated caries is not evenly distributed across the globe (Appendix Tables 3 and 6).

Some methodological issues need to be mentioned. As was true for all GBD 2010 causes, we sought to identify all relevant and high-quality data sources for untreated caries, but due to time and resource constraints, some sources may have been missed. The major challenge in reviewing the dental literature was inherent to the reporting of untreated caries. The majority of studies reported caries experience measured by the mean number of teeth that are decayed, missing, or filled. The relationship between untreated caries (DT > 0) and lifetime prevalence (DMFT > 0) is not constant and has not been quantified; as such, studies that included only DMFT > 0 data had to unfortunately be excluded, because DisMod-MR relies on fixed effects being relatively constant with respect to time and age. Therefore, we encourage researchers in public health dentistry to assess and report the total number of teeth that are decayed per person in the entire population and the proportion of the population with untreated caries. Other challenges were lack of data in certain areas of the globe and quality of published and unpublished data. Few nonrandom sample studies, otherwise sound, that were not fully representative of national, subnational, or community populations were included to address this challenge or to improve the modeling of data. This approach had minor impact on results because DisMod-MR adjusted the caries prevalence estimates by a population-weighted average correction factor in a hierarchy across super-region, region, and country.

In conclusion, untreated caries in permanent teeth remained the most prevalent health condition across the globe in 2010, affecting 2.4 billion people, and untreated caries in deciduous teeth was the 10th most prevalent condition, affecting 621 million children worldwide.

Author Contributions

N.J. Kassebaum, C.J.L. Murray, contributed to conception, design, data acquisition, analysis, and interpretation, critically revised the manuscript; E. Bernabé, contributed to data acquisition, analysis, and interpretation, drafted and critically revised the manuscript; M. Dahiya, B. Bhandari, contributed to data acquisition, critically revised the manuscript; W. Marcenes, contributed to conception, design, data acquisition, analysis, and interpretation, drafted and critically revised the manuscript. All authors gave final approval and agree to be accountable for all aspects of the work.

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