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Global Burden of Sugar-Related Dental Diseases in 168 Countries and Corresponding Health Care Costs

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Abstract

Oral diseases such as dental caries, edentulism (tooth loss), periodontal disease (PD), and oral cancer currently constitute an increased major public health burden across the globe, with significant differences between countries. One of the main drivers of caries, edentulism, and PD is the excessive intake of sugars. Here, we aimed to quantify the global sugar-related dental health and cost burden in the year 2010. This study used a health-econometrical model to calculate the disease burden as well as the direct and indirect costs attributable to the intake of free sugars (mono- and disaccharides [MDS]). To this end, several databases from the Institute for Health Metrics and Evaluation (IHME), Organisation for Economic Co-operation and Development (OECD), Food and Agriculture Organization (FAO), and World Bank were used. In total, the corresponding disease burden in 168 countries and economic burden in 31 OECD countries were quantified. In 2010, the consumption of MDS was associated with a global dental disease burden of 4.1 million disability-adjusted life years (DALYs; 95% uncertainty interval [UI]: 2.1 to 7.4 million DALYs), with 2.7 million DALYs from MDS-related caries and 1.4 million DALYs from PD. In terms of economic costs, MDS-related dental diseases were associated with a global financial burden of 172 billion US dollars (USD; 95% UI: 91 to 295 billion USD), the largest share of which (151 billion USD) was incurred in OECD countries. Overall, 26.3% (95% UI: 13.3% to 47.5%) of the total global oral disease burden was attributed to the consumption of MDS. The present study emphasizes the need to further address the role of free sugars in oral health and nutrition policy. Although the largest share of the economic burden was accounted for by OECD countries, emerging economies should address this challenge early on in national public health policies if they are to avoid disease and the prospect of increased cost burdens.

Keywords: mono- and disaccharides, oral disease burden, caries, periodontal diseases, edentulism, econometrical study

Introduction

With 3.9 billion people affected worldwide, oral health and health care is one of the urgent challenges for current and future health policies (Marcenes et al. 2013). Oral diseases, such as dental caries, edentulism (tooth loss), periodontal disease (PD), and oral cancer, currently constitute a major public health burden across the globe, with significant differences at the national level. In 2010, the most prevalent condition was untreated caries in permanent teeth, which affected 35% of the global population, or 2.4 billion people. Untreated caries in deciduous/primary teeth was the 10th most prevalent condition, affecting 9% of the world's population, or 621 million children globally (Kassebaum et al. 2015). The global number of disability-adjusted life years (DALYs) due to oral diseases rose from 10.4 million DALYs in 1990 to 17.0 million DALYs in 2015 (GBD 2015 DALYs and HALE Collaborators 2016).

Besides the impact of oral disease on an individual level through pain and suffering, the societal and health economic dimensions are of outstanding relevance. According to Listl et al. (2015), the direct medical treatment costs of dental diseases accounted for 298 billion US dollars (USD) in 2010, corresponding to an average of 4.6% of global health care expenditure. In addition, a further 144 billion USD of indirect health care costs have to be taken into account due to productivity losses. Improvements in oral health care systems may therefore not only relieve corresponding disease burdens but also lead to substantial reductions in health care expenditure.

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A supplemental appendix to this article is available online.

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Besides improper oral hygiene and insufficient public health interventions, one of the main drivers of caries and consequently tooth loss (edentulism) is the excessive intake of sugars (fermentable mono- and disaccharides [MDS]) (Fisher 1968; Jamel et al. 2004; Ruottinen et al. 2004). According to Moynihan and Kelly (2013), who conducted a systematic review to update the World Health Organization (WHO) sugar guidelines, there is consistent evidence of moderate quality, which supports a relationship between the amount of sugars consumed and the development of dental caries. Furthermore, a significant association between the intake of sugar and the prevalence of PD was described by Lula et al. (2014) in the National Health and Nutrition Examination Survey (NHANES) III cohort. In addition, high intake levels of sugar are associated not only with dental diseases but also with the development of other noncommunicable diseases such as diabetes, chronic kidney disease, and obesity/overweight-mediated comorbidities (Basu et al. 2013; Te Morenga et al. 2013; Meier et al. 2015; Saksena and Scherdel 2015; Singh et al. 2015).

Against this background, the purpose of this study was to quantify the sugar-related disease and cost burden of dental disorders.

Methods

To analyze the disease burden and the direct economic burden of MDS-related oral disorders, we expanded the health-econometrical model developed by Meier et al. (2015). Several databases were used in the model. First, to derive the attributable fraction of caries, PD, and edentulism and severe tooth loss (STL), data on the national level from the Global Burden of Disease Study for the year 2010 provided by the "GBD Compare, Viz Hub" (Institute for Health Metrics and Evaluation [IHME] 2016) were used. The following disease groups were distinguished based on the Global Burden of Disease Study (Global Burden of Disease [GBD] Study 2013 Collaborators 2015; see Appendix Table 13 with *ICD* code allotment):

- Deciduous and permanent caries
- PD
- Edentulism and STL
- Other oral diseases

To model the fraction attributable to the consumption of MDS, the pooled effect sizes from Moynihan and Kelly (2013)—concerning caries and caries-mediated edentulism and STL—and the effect sizes from Lula et al. (2014)—concerning PD and PD-mediated edentulism and STL—were used. Although an association between the disease group "other oral diseases" and the intake of MDS could not be ruled out, corresponding diseases were excluded from the MDS-related burden sharing.

Second, data were factored in concerning the oral health care coverage (OHC) for 52 countries (Hosseinpoor et al. 2012) as a proxy for the treatment of MDS-related edentulism and STL as a comorbidity of MDS-related caries and PD. Here, an inverse modeling approach was applied assuming that the nontreatment (1 – OHC) of sugar-related caries and PD mediates edentulism and STL, whereas the treatment (OHC) of sugar-related caries and PD causes corresponding treatment costs (see Appendix for a full description of the formulas used). For Germany and the United States, OHCs were used from Destatis (2016) and the National Institute of Dental and Craniofacial Research (2016), respectively. For the remaining countries, corresponding weighted averages were calculated, distinguishing between the country groups based on the World Development Report 2005 (World Bank 2005). A full list of the country-specific OHCs and the country group allotment can be found in the supporting material (Appendix Tables 2 and 3).

Third, as a proxy for the actual intake of MDS, supply data were factored in from FAO Stat (2016) for "sugar, refined equivalent" (FAO code: 2818) and "sweeteners, other" (FAO code: 2543) for the year 2010. Here, "sugar, refined equivalent" includes "164 sugar refined, centrifugal from 157 sugar beet and 158 sugar cane, 168 Sugar Confectionery, 171 Sugar flavoured." "Sweeteners, other" includes "154 Fructose chemically pure, 155 Maltose chemically pure, 160 Maple sugar and syrups, 161 Sugar crops, nes, 166 Fructose and syrup, other, 167 Sugar, nes, 172 Glucose and dextrose, 173 Lactose, 175 Isoglucose, 633 Beverages, non-alcoholic, 165 Molasses" (http://faostat3.fao.org/mes/classifications/E).

Fourth, we extracted the total direct oral health care costs for 28 Organisation for Economic Co-operation and Development (OECD) countries from the OECD data set "Health Expenditure and Financing"—expressed in current purchasing power parity (PPP) USD in the year 2010 (OECD 2016). As this database has several shortcomings in terms of its scope and data quality, all entries were checked and, if necessary, replaced by officially reported numbers from national statistics. Since the OECD data set does not provide data for 2010 for Ireland, Italy, and the United Kingdom, corresponding oral health care expenditure figures were extracted from other sources to finally consider 31 countries in the analysis. Table 1 provides an overview of the total direct oral health care expenditures in the OECD countries considered and the corresponding data sources. Since no appropriate data on oral health care expenditures were available for Chile, Portugal, or Turkey, these countries were omitted from the OECD-specific analysis. All direct costs considered comprise all reported expenditures by the provider of dental practices for dental services, including public and private sources of funds for treatment, prevention, and medication, as specified in the International Classification of Health Accounts (categories: HC.1.3.2, "outpatient dental care"; HP.3.2, "offices of dentists"; OECD, Eurostat, WHO 2011). Expenditures related to other oral health care providers (hospitals; retailers and other providers of medical goods; providers of ancillary services, preventive care, and health care system administration) were not considered in the study. As reference the year 2010 was chosen, as during study execution (May to July 2016) for the year 2010, the most coherent data were available (in terms of disease burden as well as in terms of sugar supply and oral health care costs).

Table 1. Direct Oral Health Care Expenditure in 2010.

Country	Direct Oral Health Care Expenditure in Billion USD	Direct Oral Health Care Expenditure per Person in USD	Data Sources and Explanations
Australia	8.04	364.8	Australian Institute of Health and Welfare (2012)
Austria	1.80	215.2	OECD (2016)
Belgium	1.52	139.1	OECD (2016)
Canada	10.09	296.8	OECD (2016), data from 2009
Czech Republic	1.09	104.5	OECD (2016)
Denmark	1.43	252.2	OECD (2016)
Estonia	0.12	87.9	OECD (2016)
Finland	0.56	104.3	OECD (2016)
France	11.31	173.9	OECD (2016)
Germany	28.08	343.3	OECD (2016)
Greece	2.38	214.4	OECD (2016)
Hungary	0.51	51.3	OECD (2016)
Iceland	0.011	33.5	Statistics Iceland (2016)
Ireland	0.78	171.3	Central Statistics Office (2015)
Israel	1.29	168.9	OECD (2016)
Italy	17.39	293.4	Patel (2012)
Japan	23.85	186.2	OECD (2016)
Luxembourg	0.15	291.7	OECD (2016)
Mexico	3.34	28.1	OECD (2016)
Netherlands	3.43	206.4	OECD (2016)
New Zealand	0.36	81.6	OECD (2016), data from 2007
Norway	1.35	275.2	OECD (2016)
Poland	2.28	59.9	OECD (2016)
Slovakia	0.45	83.9	OECD (2016)
Slovenia	0.18	86.2	OECD (2016)
South Korea	7.02	286.7	OECD (2016)
Spain	10.48	225.0	OECD (2016)
Sweden	2.59	276.4	OECD (2016), data from 2011
Switzerland	4.05	518.2	Swiss Federal Statistical Office (2015)
United Kingdom	12.42	197.6	Patel (2012)
United States	105.38	340.6	OECD (2016)
Rest of the world	33.96	5.8	Obtained via difference calculation from Listl et al. (2015)
WORLD	297.67	43.0	
OECD	263.71	236.1	

OECD, Organisation for Economic Co-operation and Development; USD, US dollars.

Analysis of Indirect Costs

The indirect costs were analyzed according to the WHO (2001). This approach is based on valuing one DALY at 1 y of per capita gross domestic product (GDP) to approximate productivity losses. Following this approach, we used current 2010 values of GDP per capita (World Bank 2016) and corresponding MDS-related DALYs for caries, PD, and edentulism and STL, calculated as presented above. This widely applied approach estimating indirect welfare losses was used to estimate the global economic costs of cancer (John and Ross 2010) and the global indirect costs of oral diseases (Listl et al. 2015).

Uncertainty and Sensitivity Analyses

As the results of this study rely on distinct data sources and studies with different study designs, sensitivity and uncertainty checks were conducted to prove the validity of the results. The uncertainty was gauged by analyzing for all results the 95% uncertainty interval (UI) based on the DALYs provided by IHME (2016) for all oral diseases considered. It must be taken into account that data from IHME (2016) is not based on a frequentist but on a Bayesian statistical data analysis (Flaxman et al. 2015). To reflect shortcomings in the FAO food supply data (FAO Stat 2016), in a sensitivity analysis, all calculations in formulae (1) and (2) were conducted without the factor $\frac{MDS_i}{\overline{MDS}}$ (see Appendix).

Results

In 2010, MDS-related dental disorders were associated with a global disease burden of 4.1 million DALYs (95% UI: 2.1 to 7.4 million DALYs). On the national level, the highest absolute MDS-related disease burden was observed for India, with 0.75 million DALYs (95% UI: 0.39 to 1.3 million DALYs), including 0.56 million DALYs from caries and caries-mediated edentulism and STL as well as 0.19 million DALYs from PD and

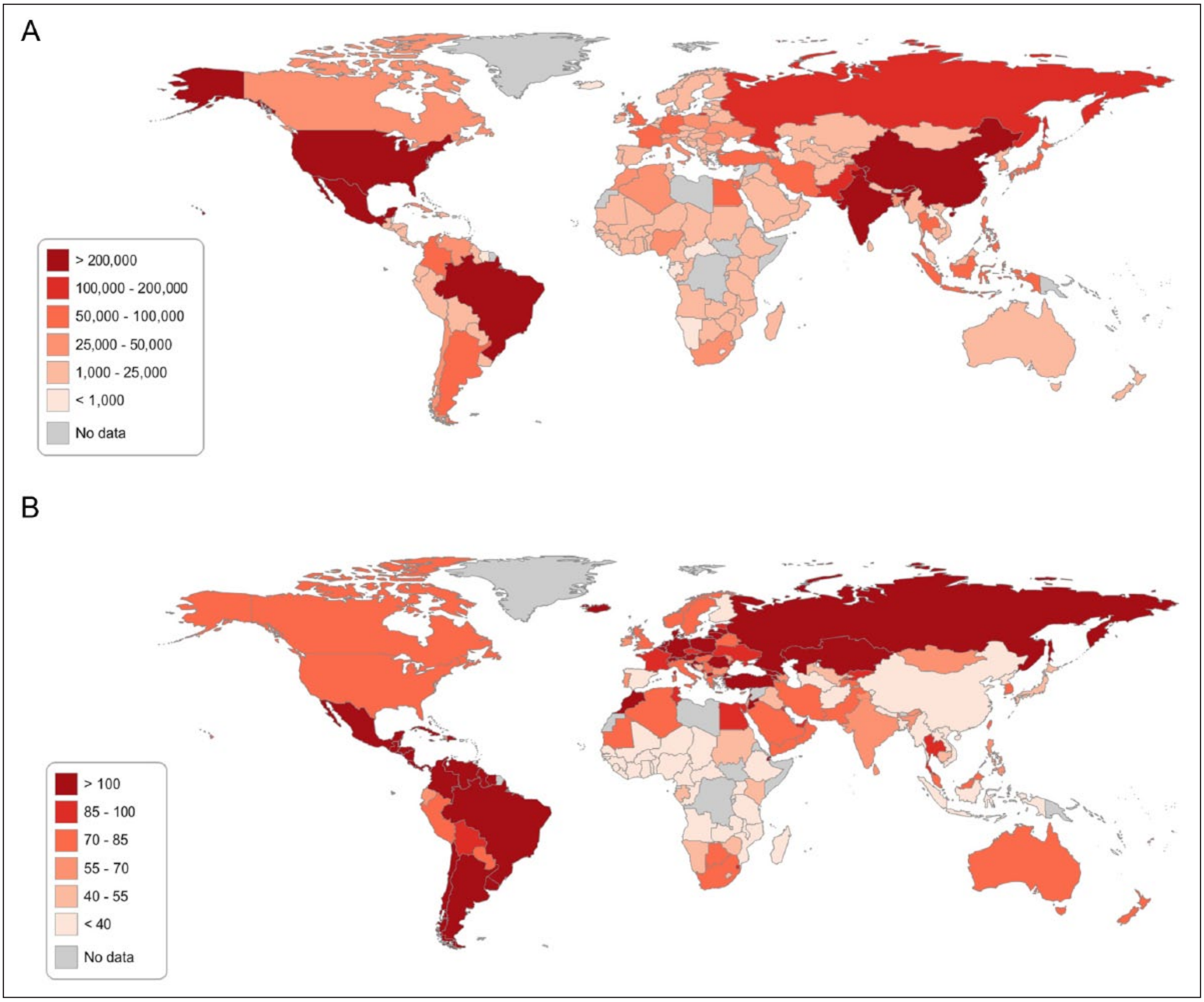

Figure 1. Map of mono- and disaccharide (MDS)–related disorders. (**A**) MDS-related dental disorders caused by caries, periodontal disease (PD), edentulism, and severe tooth loss (STL) in absolute disability-adjusted life years (DALYs) in the year 2010. (**B**) MDS-related dental disorders caused by caries, PD, edentulism, and STL in DALYs per 100,000 in 2010 (age-standardized).

PD-mediated edentulism and STL. China, the United States, Brazil, and Mexico ranked second, third, fourth, and fifth, respectively, with 0.263 million DALYs, 0.257 million DALYs, 0.240 million DALYs, and 0.230 million DALYs. Whereas in the OECD countries considered, the corresponding disease burden accounted for 1.0 million DALYs (95% UI: 0.5 to 1.9 million), in the rest of the world, 3.1 million DALYs (95% UI: 1.6 to 5.5 million DALYs) were due to the consumption of MDS (Fig. 1A; Appendix Tables 2 and 11). The highest age-standardized DALY rates per 100,000 were observed for Cuba (252; 95% UI: 127 to 453), Chile (249; 95% UI: 125 to 454), and Argentina (235; 95% UI: 117 to 425) (Fig. 1B; Appendix Table 2). In relative terms, at 73%, the highest share of MDS-related dental diseases was identified for Guatemala, along with 69% for Mauretania, Mexico, and Costa Rica and 67% for Honduras. The lowest share, 2.3%, was observed for Myanmar, followed by Nepal (6.2%), North Korea (8.4%), Central African Republic (8.6%), and Bangladesh (8.9%) (Fig. 2; Appendix Tables 4 and 6).

In terms of economic costs, MDS-related dental disorders were associated with a global financial burden of 172 billion USD (95% UI: 91 to 295 billion USD), the largest share of which (151 billion USD) was incurred in OECD countries. This figure of 151 billion USD (95% UI: 81 to 261 billion USD) included 98.6 billion USD of direct oral health care expenditure and 52.1 billion USD of indirect costs resulting from productivity losses in the labor market. In the country group "rest of the world," 8.7 billion USD were attributed to direct MDS-related dental disorders, whereas 12.5 billion USD resulted from indirect costs (Appendix Table 11). In Table 1, the data sources concerning the total direct oral health care expenditures (on national and per capita level) are presented.

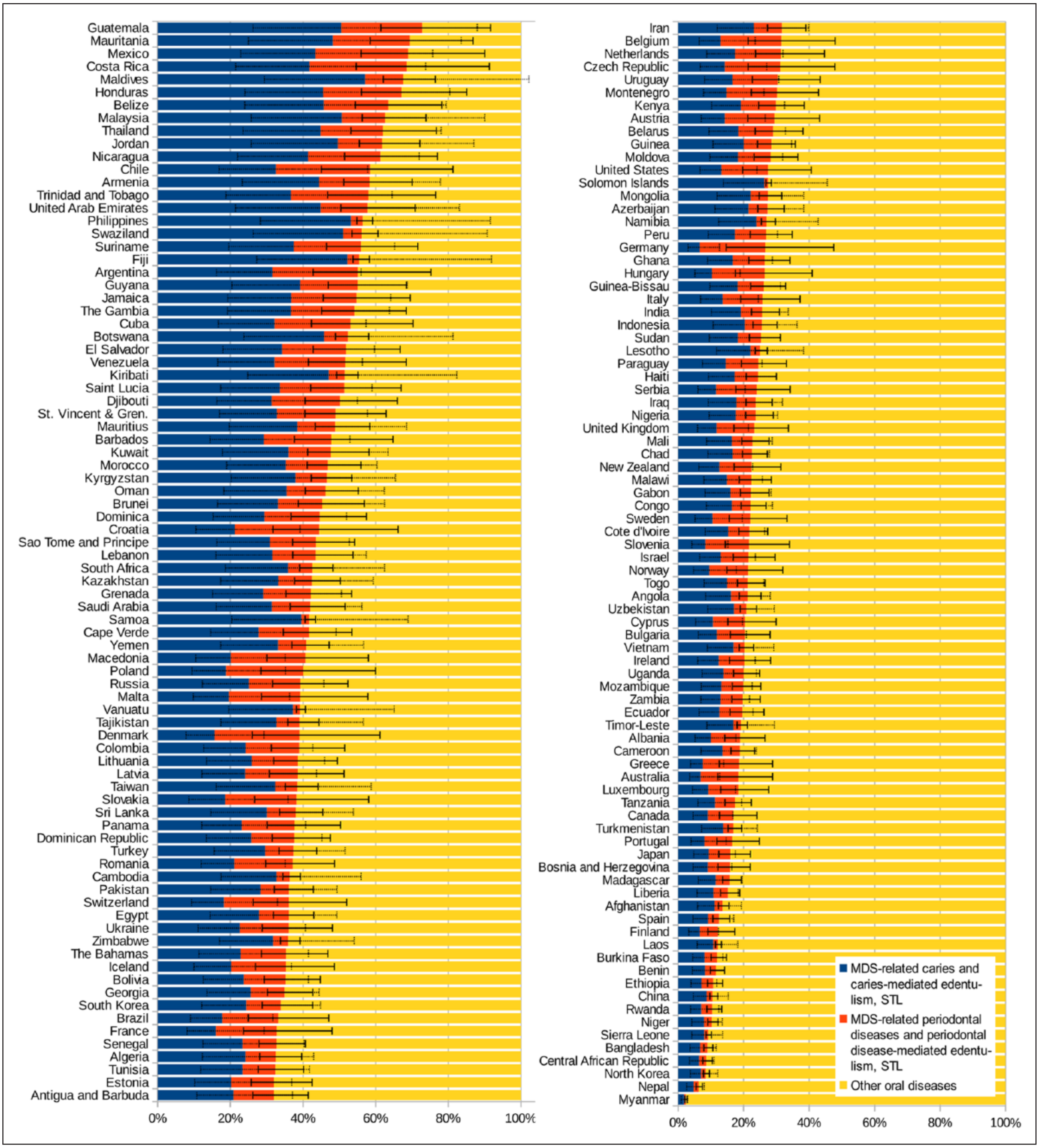

Figure 2. Share of mono- and disaccharide (MDS)–related dental diseases in 2010 in terms of the total oral disease burden (including 95% uncertainty interval). Dotted intervals denote caries and corresponding edentulism and severe tooth loss (STL); solid lines denote periodontal disease and corresponding edentulism and STL.

On the disease level, the highest burden was caused by MDS-related caries and caries-mediated edentulism and STL, accounting for 86 billion USD (95% UI: 46 to 144 billion USD), which included 53.0 billion USD of direct oral health care expenditure and 33.4 billion USD of indirect costs. MDS-related PD and PD-mediated edentulism and STL caused a financial burden of 85 billion USD (95% UI: 44 to 151 billion USD), of which direct expenditure accounted for 54.3 billion USD and indirect costs for 31.2 billion USD. All in all, 35.4% (95% UI: 18.7% to 60.8%) of the total global cost

Table 2. Global Direct and Indirect Health Care Costs of MDS-Related Dental Disorders in 2010.

	Direct Costs						Indirect Costs				
Country	Total Direct Oral Health Care Expenditure (Billion USD)	MDS-Related Costs Due to Caries and Caries-Mediated Edentulism and STL (Billion USD)	95% UI	MDS-Related Costs Due to PD and PD-Mediated Edentulism, STL (Billion USD)	95% UI	GNI per Capita, Current USD	Total Indirect Oral Health Care Costs (Billion USD)	MDS-Related Costs Due to Caries and Caries-Mediated Edentulism, STL (Billion USD)	95% UI	MDS-Related Costs Due to PD and PD-Mediated Edentulism, STL (Billion USD)	95% UI
Australia	8.04	0.77	0.43-1.32	1.29	0.67-2.26	46,530	4.00	0.38	0.21-0.66	0.64	0.33-1.12
Austria	1.80	0.36	0.19-0.62	0.38	0.20-0.67	49,350	1.51	0.30	0.16-0.52	0.32	0.16-0.56
Belgium	1.52	0.27	0.15-0.46	0.39	0.20-0.68	47,700	1.81	0.33	0.18-0.55	0.47	0.24-0.82
Canada	10.09	1.27	0.69-2.17	1.11	0.57-1.94	44,450	6.59	0.83	0.45-1.42	0.72	0.37-1.27
Czech Republic	1.09	0.28	0.16-0.46	0.33	0.17-0.56	19,210	0.57	0.14	0.08-0.24	0.17	0.09-0.29
Denmark	1.43	0.31	0.17-0.54	0.46	0.24-0.83	60,820	1.06	0.23	0.13-0.40	0.35	0.18-0.62
Estonia	0.12	0.03	0.02-0.06	0.02	0.01-0.03	14,580	0.06	0.02	0.01-0.03	0.01	0.00-0.02
Finland	0.56	0.06	0.03-0.10	0.05	0.02-0.08	49,330	0.87	0.09	0.05-0.15	0.07	0.04-0.13
France	11.31	2.52	1.38-4.29	2.63	1.35-4.64	43,790	7.96	1.77	0.97-3.02	1.85	0.95-3.27
Germany	28.08	3.66	2.07-6.07	11.23	6.02-19.22	44,790	15.39	2.01	1.13-3.33	6.16	3.3-10.54
Greece	2.38	0.25	0.14-0.43	0.37	0.19-0.65	27,600	1.21	0.13	0.07-0.22	0.19	0.10-0.33
Hungary	0.51	0.08	0.04-0.13	0.12	0.06-0.21	13,090	0.38	0.06	0.03-0.10	0.09	0.05-0.15
Iceland	0.011	0.003	0.002-0.005	0.002	0.001-0.004	36,670	0.035	0.010	0.005-0.017	0.007	0.004-0.013
Ireland	0.78	0.16	0.09-0.28	0.10	0.05-0.18	44,740	0.57	0.12	0.07-0.20	0.08	0.04-0.13
Israel	1.29	0.23	0.13-0.39	0.15	0.08-0.27	29,460	0.59	0.11	0.06-0.18	0.07	0.04-0.13
Italy	17.39	3.28	1.78-5.53	2.96	1.51-5.26	37,700	6.35	1.20	0.65-2.02	1.08	0.55-1.92
Japan	23.85	3.11	1.73-5.38	2.21	1.15-3.9	41,980	14.61	1.90	1.06-3.30	1.35	0.71-2.39
Luxembourg	0.15	0.02	0.01-0.04	0.02	0.01-0.04	79,520	0.13	0.02	0.01-0.04	0.02	0.01-0.04
Mexico	3.34	1.46	0.77-2.54	0.86	0.42-1.57	8,650	2.89	1.26	0.67-2.20	0.74	0.37-1.36
Netherlands	3.43	0.83	0.46-1.42	0.67	0.34-1.19	53,530	3.39	0.82	0.45-1.40	0.66	0.34-1.18
New Zealand	0.36	0.06	0.03-0.11	0.05	0.03-0.09	29,390	0.44	0.08	0.04-0.13	0.06	0.03-0.11
Norway	1.35	0.18	0.10-0.31	0.22	0.12-0.39	88,430	1.58	0.21	0.11-0.36	0.26	0.14-0.46
Poland	2.28	0.60	0.33-1.03	0.67	0.35-1.20	12,710	1.38	0.36	0.20-0.62	0.41	0.21-0.72
Slovakia	0.45	0.15	0.09-0.26	0.16	0.09-0.28	17,180	0.25	0.09	0.05-0.14	0.09	0.05-0.16
Slovenia	0.18	0.02	0.01-0.03	0.03	0.02-0.06	24,560	0.15	0.02	0.01-0.03	0.03	0.01-0.05
South Korea	7.02	2.38	1.30-4.09	0.93	0.48-1.65	21,320	2.26	0.77	0.42-1.31	0.30	0.16-0.53
Spain	10.48	1.43	0.80-2.45	0.54	0.28-0.95	32,130	3.99	0.55	0.30-0.93	0.20	0.11-0.36
Sweden	2.59	0.43	0.24-0.72	0.47	0.25-0.82	53,900	1.86	0.31	0.17-0.52	0.34	0.18-0.59
Switzerland	4.05	1.03	0.57-1.73	1.01	0.52-1.76	77,360	2.20	0.56	0.31-0.94	0.55	0.28-0.96
United Kingdom	12.42	2.02	1.12-3.44	2.01	1.05-3.49	40,480	8.74	1.42	0.79-2.42	1.41	0.74-2.46
United States	105.38	19.23	10.60-32.74	20.69	10.75-36.88	48,950	45.84	8.36	4.61-14.24	9.00	4.67-16.04
OECD	263.71	46.49	25.64-79.14	52.13	27.19-91.77	37,610	138.64	24.44	13.47-41.63	27.69	14.43-48.69
Rest of the world	33.96	6.51	2.70-7.01	2.15	0.87-4.39	4,064	48.95	8.95	4.68-15.73	3.51	1.70-6.50
SUM	297.67	53.00	28.34-86.15	54.28	28.06-96.16		187.60	33.39	18.15-57.36	31.20	16.13-55.19

GNI, gross national income; MDS, mono- and disaccharides; OECD, Organisation for Economic Co-operation and Development; PD, periodontal disease; STL, severe tooth loss; UI, uncertainty interval; USD, US dollars.

burden and 26.3% (95% UI: 13.3% to 47.5%) of the total global disease burden could be attributed to MDS-related dental disorders.

On the national level within OECD countries, the highest absolute MDS-related cost burden was observed for the United States, at 57.3 billion USD (95% UI: 30.6 to 99.9 billion USD), including 39.9 billion USD of direct health care expenditure and 17.4 billion USD of indirect costs. Germany, France, Japan, and Italy came second, third, fourth, and fifth, respectively, with 23.1 billion USD, 8.8 billion USD, 8.6 billion USD, and 8.5 billion USD. See Table 2 and Figure 3 for a full list of OECD countries considered.

On a per capita basis, total MDS-related dental health care costs varied between 402 USD per capita per year in Switzerland (95% UI: 216 to 689 USD) and 34.0 USD in Hungary (95% UI: 18.0 to 58.6 USD). Besides Switzerland, in the following countries, a high MDS-related cost burden was observed (in descending order): Germany, 282 USD (95% UI: 153 to 479 USD); Denmark, 239 USD (95% UI: 125 to 421 USD); United States, 185 USD (95% UI: 99 to 323 USD); and Luxembourg, 181 USD (95% UI: 99 to 308 USD). Whereas the average per capita burden in OECD countries was 135 USD of MDS-related costs (95% UI: 72 to 234 USD), the rest of the world faced 3.6 USD (95% UI: 1.7 to 5.8 USD). See Appendix Table 8 for a full list of MDS-related dental health care expenditure figures.

Discussion

In this study, we showed that in 2010, the consumption of MDS was associated with a dental disease burden of 4.1 million DALYs (95% UI: 2.1 to 7.4 million DALYs) globally, with 1.9 million DALYs from MDS-related caries, 1.0 million DALYs from MDS-related PD, and 1.2 million DALYs from MDS-related edentulism and STL, as a cause of MDS-related caries and PD (see Appendix Table 5). In terms of economic costs, MDS-related dental diseases were associated with a global financial burden of 172 billion USD (95% UI: 91 to 295 billion USD). Compared to the total global disease burden

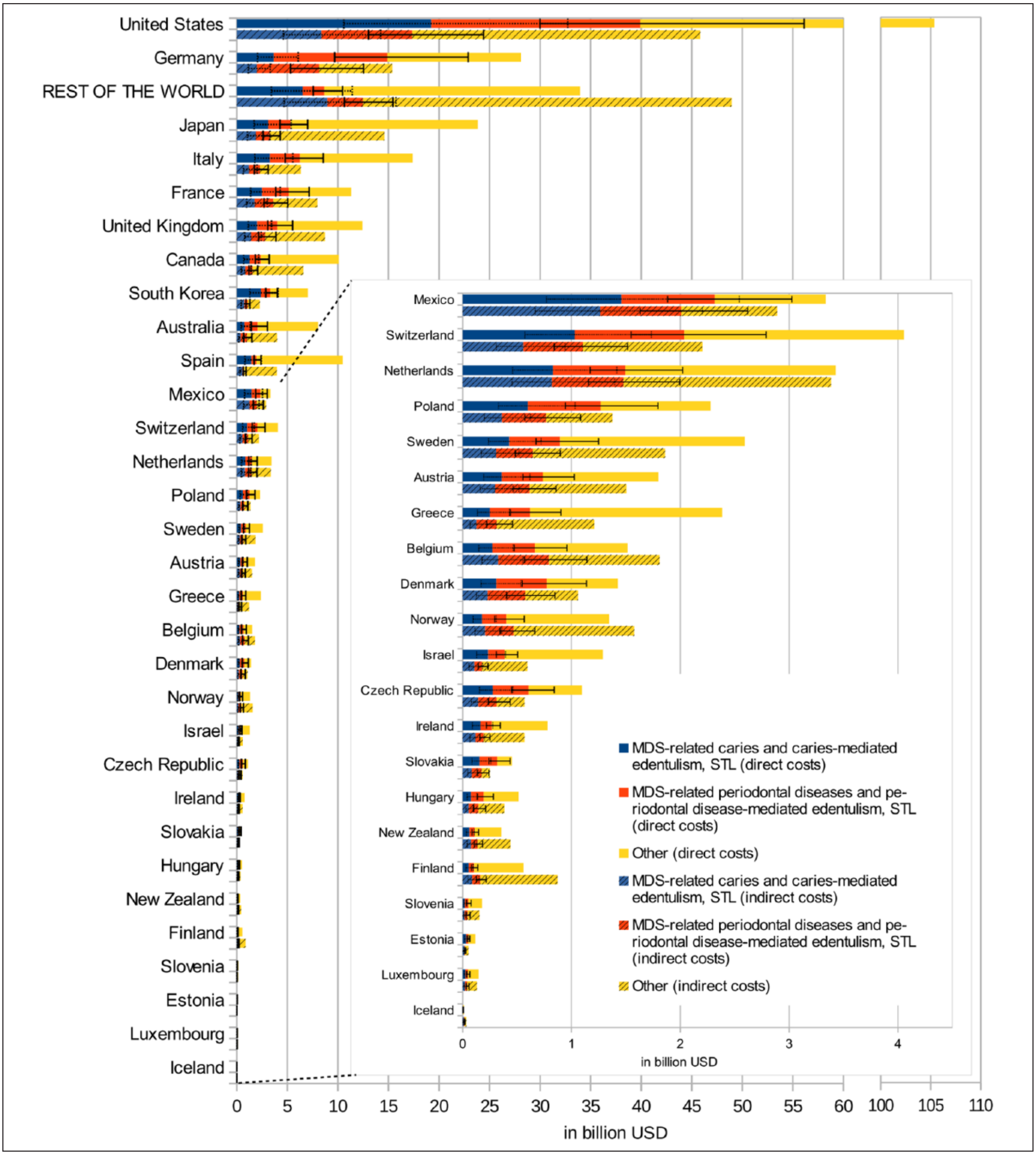

Figure 3. Direct and indirect health care costs of mono- and disaccharide (MDS)–related dental diseases in 2010, direct costs in descending order (including 95% uncertainty interval). Dotted intervals denote caries, corresponding edentulism, and severe tooth loss (STL); solid lines denote periodontal disease, corresponding edentulism, and STL.

(2.5 billion DALYs in 2010), the total oral disease burden (15.6 million DALYs) and the MDS-related disease burden (4.1 million DALYs) are of minor importance (attributable fractions: 0.63% and 0.16%, respectively). However, in terms of dietary risks, the excessive consumption of MDS, with 4.1 million DALYs in 2010, is of higher importance than a diet high in sugar-sweetened beverages (1.3 million DALYs), a diet high in red meat (1.6 million DALYs), a diet low in milk (2.4 million

DALYs), and a diet suboptimal in calcium (3.0 million DALYs) and ranks—compared to all dietary risk factors—11th position (out of 15). With regards to the total diet-related disease burden in 2010 (249 million DALYs), the identified disease burden of MDS-related dental diseases (4.1 million DALYs) has a share of 1.62% (IHME 2016). However, compared to the total oral burden causing 15.6 million DALYs and 485.3 billion USD in 2010, the fraction attributable to the excessive consumption of MDS is with 4.1 million DALYs (26.3%) and 172 billion USD (35.4%) of political importance. Moreover, in light of a further round of sugar market liberalization expected in 2017 (expiry of the European sugar market regime) and the resulting abundance of cheap sugars (mainly as fructose/glucose syrups) expected on regional and global markets, sugar-induced diseases and comorbidities beyond oral diseases—like cardiovascular diseases, diabetes, and obesity-mediated cancers—may gain a new and unprecedented momentum, which might be mitigated by proper health policy interventions based on sound, scientific and evidence-based assessments framing both oral and systemic diseases (Lee and Giannobile 2016; Jin et al. 2016; Schwendicke et al. 2016). Although from an epidemiological point of view, it is not possible to derive an optimal intake level of free sugars, current WHO recommendations (WHO 2015) to reduce the intake of free sugars to 10% (strong recommendation) or 5% (conditional recommendation) of a person's daily energy intake can be used as a guide.

The originality and strength of this study lies in the risk factor–specific assessment of the disease burden and economic burden associated with the consumption of MDS in 168 countries, with a special focus on OECD countries. To our knowledge, we quantified for the first time the corresponding disease burden as well as the direct and indirect health care costs and tested the robustness of the results in uncertainty and sensitivity analyses. In our disease burden and cost model, we took into account several factors deriving from representative data sets with a global or regional coverage (for a detailed description, see Methods). However, the following potential limitations should be considered in the interpretation of our findings.

First, when it came to the analysis of direct costs, relevant information was identified for only 31 OECD countries. For the category "rest of the world," data from just 35 countries were used from Listl et al. (2015) to generate a rough estimate of corresponding direct dental treatment costs. As such, for the country group "rest of the world," our results entail a considerable degree of uncertainty when estimating MDS-related costs of dental diseases. Concerning the sum of the indirect costs ("Total indirect oral health care costs" in Table 2), our result (187.6 billion USD) varies from that of Listl et al. (2015) (144 billion USD), as here the disease category "other oral diseases" was included. On the other hand, as regards the disease burden of MDS-related dental disorders for 168 countries, data from the GBD study (IHME 2016) were used, which is considered more robust since it is based on the largest and most comprehensive database for global health monitoring.

Second, with regard to Andorra, Bahrain, Bhutan, Burundi, Comoros, Congo, Equatorial Guinea, Eritrea, Micronesia, Libya, Marshall Islands, Palestine, Papua New Guinea, Qatar, Seychelles, Singapore, Somalia, South Sudan, Syria, and Tonga, no country-level details are provided in this study since these countries are not documented in the food balance sheets database of the FAO Stat (2016). Since there is no global database of real intake levels of food/nutrients currently available, data from FAO Stat (2016) concerning the supply of MDS on a national level were used in the model as a proxy for the intake of MDS. However, although an association between the supply of MDS and oral diseases can be observed (Appendix Fig. 1; Table 3), FAO supply levels tend to be roughly one-third higher than actual intake levels. To quantify the impacts resulting from limitations of the FAO food supply data, in a quantitative sensitivity analysis, all calculations with formulae (1) and (2) were conducted without the factor $\frac{MDS_i}{\overline{MDS}}$ (see Appendix). As Del Gobbo et al. (2015) have shown, data from the FAO food balance sheets can deviate by between −50% and +270% from intake data obtained in nutrition surveys (for further details concerning the difference of intake and consumption/supply data, see Meier and Christen [2013] and Meier et al. [2014]). In the future, it may be possible to use data from more precise intake or nutrient databases, such as the Global Dietary Database (Micha et al. 2015; Singh et al. 2015) or the GENuS nutrient database (Smith et al. 2016), which are currently under construction.

Third, we have combined epidemiological evidence for risk factors (Moynihan and Kelly 2013; Lula et al. 2014) using studies across different populations and periods, which could mask underlying spatial and temporal changes in risk. Whereas Moynihan and Kelly (2013) performed a pooled meta-analysis regarding the consumption of sugars and the prevalence of caries, Lula et al. (2014) used only one cohort to quantify the impact of the consumption of added sugars on PD. Although adjusted for several confounders (sex, age, race-ethnicity, education, poverty-income ratio, tobacco exposure, previous diagnosis of diabetes, body mass index), the effect sizes derived from Lula et al. (2014) are based on a subpopulation of the NHANES III cohort including 2,437 participants 18 to 25 y old. Although pooled effect sizes concerning MDS intake and the prevalence of gingivitis are documented (Hujoel 2009), no further studies exist quantifying the impact of MDS consumption on PD. Future research should focus more systematically on this risk-outcome pair.

Fourth, only expenditures arising in dental practices, including public and private sources for treatment, prevention, and medication, were considered in the analysis. Due to a lack of data, oral health care expenditures of other providers (hospitals; retailers and other providers of medical goods; and providers of ancillary services, preventive care, and health care system administration) were not considered in the study. Hence, actual direct oral health care costs related to the consumption of MDS might globally exceed the 107.3 billion USD (95% UI: 56.4 to 182.3) identified in this study. Furthermore, the modeling approach used for the calculation of MDS-related caries and PD (Appendix formulae (1) and (2)) and MDS-related edentulism and STL (Appendix formulae (3) and (4)) does not distinguish between preventive and restorative dental care. Future updates of the OECD statistical database (OECD 2016) should include corresponding cost categories, which would allow such a disaggregated evaluation.

Conclusion

This study emphasizes the need to further address the role of free sugars in oral health and nutrition policy. Although in 2010 the largest share of the economic burden was accounted for by OECD countries, emerging economies should address this challenge properly early on in national policies if they are to avoid disease and the prospect of increased cost burdens. However, to allow a proper monitoring of the impact of current and future policy interventions, it would be necessary to include MDS-related oral disease burdens in corresponding policy evaluation schemes. These could, for example, be included in the meta-regression framework of the Global Burden of Disease study (IHME 2016). Epidemiological studies have broadly shown that public health interventions, like the fluoridation of water, toothpaste, and salt, are at least as good as reducing sugar intake levels.

Author Contributions

T. Meier, contributed to conception, design, data acquisition, analysis, and interpretation, drafted the manuscript; P. Deumelandt, K. Riedel, M. Langer, contributed to conception and design, critically revised the manuscript; O. Christen, G.I. Stangl, contributed to data interpretation, critically revised the manuscript. All authors gave final approval and agree to be accountable for all aspects of the work.

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