Dunleavy et al. BMC Public Health (2024) 24:3239
https://doi.org/10.1186/s12889-024-20652-0

BMC Public Health

RESEARCH

Open Access

Inequalities in oral health: estimating the longitudinal economic burden of dental caries by deprivation status in six countries

Gerard Dunleavy[1*], Neeladri Verma[1], Radha Raghupathy[2], Shivangi Jain[1], Joao Hofmeister[1], Rob Cook[1], Marko Vujicic[3], Moritz Kebschull[4,5,6,7,8], Iain Chapple[4,6,7,8], Nicola West[9†] and Nigel Pitts[10†]

Abstract

Background The recent World Health Organization (WHO) resolution on oral health urges pivoting to a preventive approach and integration of oral health into the non-communicable diseases agenda. This study aimed to: 1) explore the healthcare costs of managing dental caries between the ages of 12 and 65 years across socioeconomic groups in six countries (Brazil, France, Germany, Indonesia, Italy, UK), and 2) estimate the potential reduction in direct costs from non-targeted and targeted oral health-promoting interventions.

Methods A cohort simulation model was developed to estimate the direct costs of dental caries over time for different socioeconomic groups. National-level DMFT (dentine threshold) data, the relative likelihood of receiving an intervention (such as a restorative procedure, tooth extraction and replacement), and clinically-guided assumptions were used to populate the model. A hypothetical group of upstream and downstream preventive interventions were applied either uniformly across all deprivation groups to reduce caries progression rates by 30% or in a levelled-up fashion with the greatest gains seen in the most deprived group.

Results The population level direct costs of caries from 12 to 65 years of age varied between US10.2 billion in Italy to US$36.2 billion in Brazil. The highest per-person costs were in the UK at US$22,910 and the lowest in Indonesia at US$7,414. The per-person direct costs were highest in the most deprived group across Brazil, France, Italy and the UK. With the uniform application of preventive measures across all deprivation groups, the greatest reduction in per-person costs for caries management was seen in the most deprived group across all countries except Indonesia. With a levelling-up approach, cost reductions in the most deprived group ranged from US$3,948 in Indonesia to US$17,728 in the UK.

Conclusion Our exploratory analysis shows the disproportionate economic burden of caries in the most deprived groups and highlights the significant opportunity to reduce direct costs via levelling-up preventive measures. The healthcare burden stems from a higher baseline caries experience and greater annual progression rates in the most deprived. Therefore, preventive measures should be start early, with a focus on lowering early childhood caries and continue through the life course.

†Nicola West and Nigel Pitts contributed equally to this work.

*Correspondence:
Gerard Dunleavy
gerarddunleavy@economist.com
Full list of author information is available at the end of the article

Keywords Oral health, Dental caries, Inequalities, Economic burden, Prevention, Non-communicable diseases, Public health, Socioeconomic

Background

Dental caries affect about 2 billion people worldwide and is the most common non-communicable disease [1, 2]. The main risk factors for dental caries include a high intake of refined sugars, poor oral hygiene, and inadequate exposure to fluoride — all of which are preventable [3]. Yet, preventive approaches are lacking and the burden of caries is rising. The total number of individuals with dental caries (dentine cavity threshold) has risen by 46% between 1990 and 2019; mostly attributable to population change, urbanisation, and lifestyle changes [4].

The impact of the rising dental caries prevalence is disproportionately higher among socioeconomically deprived groups. The Global Burden of Disease (GBD) 2019 data showed that dental caries prevalence in both deciduous and permanent teeth was higher in countries with a lower Social Development Index (SDI) [2]. A systematic review of 41 studies, including adults between 19 and 60 years of age, showed that lower educational attainment, income, socioeconomic status at an individual level, and a higher Gini coefficient at the country level were associated with a higher prevalence of caries [5]. This suggests that inequality, both at the individual and societal level, plays a critical role in the distribution of dental caries.

At the individual level, lifestyle factors such as inadequate oral hygiene, lack of awareness, and poor access to dental care are significant contributors to these inequalities. However, these issues are often compounded by broader societal factors. In deprived areas, people are more likely to consume foods and beverages with higher refined sugar content [6]. The marketing activities of private companies promoting tobacco, alcohol, high-sugar sweets and beverages more purposefully target lower-middle income countries, emerging economies and deprived populations [1]. These population segments are particularly vulnerable due to food insecurity, poor access to nutritious food choices, and may also be dependent on these companies for employment and income [7]. Foods with a high refined sugar content are more readily available in deprived neighbourhoods and usually cheaper than more nutritious alternatives. Thus, the cycle of malnutrition and dental caries continues in the twenty-first century [8]. Deprived populations also have poor access to oral health promotion efforts and dental services [9].

Both upstream and downstream preventive measures have been shown to lower dental caries risk. Community water fluoridation is a cost-effective population health strategy to reduce caries [10, 11]. Data from a cross-sectional study in the United States has shown that water fluoridation can also narrow the gap in dental caries prevalence between different socioeconomic classes in children with deciduous teeth [12]. However, children in lower socioeconomic groups are less likely to live in localities with fluoridated water [12]. The implementation of taxation on sugar-sweetened beverages (SSB) has also demonstrated efficacy in lowering sugar consumption and dental caries risk at a population level, which could potentially be more impactful among the most socioeconomically deprived in society [13, 14]. However, only 57% of the global population lives in countries where taxes on SSBs are implemented [15]. Furthermore, the applied excise tax is relatively small, accounting on average for approximately 6.6% of the price of 330 ml soda. Additionally, 46% of countries that impose SSB taxes also apply similar taxation to unsweetened bottled water [1].

At an individual level, improved oral hygiene and reduced consumption of foods and drinks that contain high sugar content levels are key factors in reducing dental caries [16]. Tooth brushing twice daily with toothpaste containing 1000-1500 ppm of fluoride, albeit a simple measure, remains inaccessible to many low-income communities [17]. Topical fluoride applications have proven effective in caries prevention. The application of topical fluoride varnish forms a protective layer of fluorapatite on teeth, which can resist demineralisation and further enhance remineralisation, preventing caries progression [18]. Similarly, the application of silver diamine fluoride (SDF) increases the pH of biofilm, reduces dentin demineralization, and has antimicrobial action against cariogenic bacteria [19]. Another effective preventive measure is the use of fissure sealants, which work as a physical barrier to seal deep fissures preventing food and bacterial accumulation with subsequent caries formation [18]. A study performed in the North West of England between 1990 and 1999 showed that children from more deprived communities were less likely to receive professional fluoride varnish application; yet, there is a lack of more recent data on this important preventive measure [20]. While preventive measures are effective in lowering the dental caries burden, they remain less accessible to the most deprived, who remain the most severely impacted.

There is limited data on the economic burden of caries and the available information is dated. Global

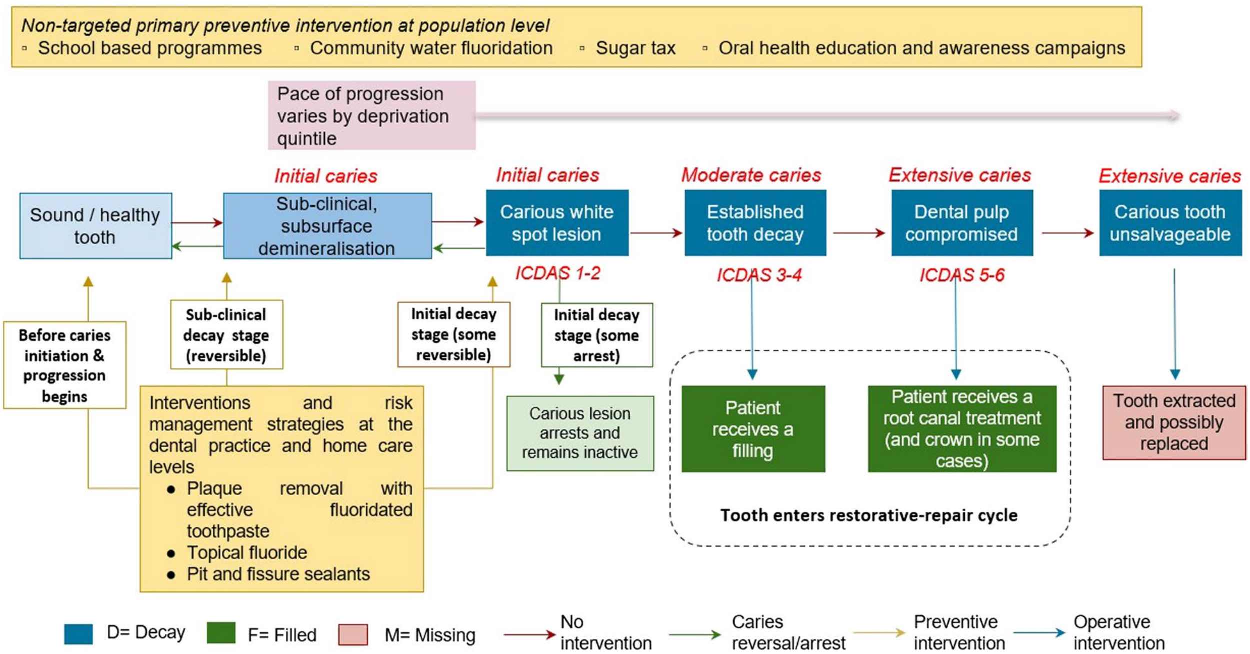

Fig. 1 Conceptual framework of dental caries pathway of care

estimates in 2015 suggested that the total worldwide costs of oral and dental diseases amounted to approximately US$544 billion. Of this, approximately 45% ($245 billion), was estimated to be due to dental caries [21, 22]. Data from England in 2021–2022 showed that £81 million was spent on tooth extractions for children less than 19 years of age, the majority of which were due to dental caries [23]. However, there is a lack of data on the long-term costs of dental caries among adults. The effect of instituting early prevention and management measures on bridging socioeconomic inequities and reducing direct costs remains to be studied.

Here we report a Caries Prevention and Care Cost Calculator that we have developed to: 1) longitudinally determine the direct costs for managing dental caries between 12 and 65 years of age and 2) the potential reduction in direct costs from universal and targeted oral health promotion interventions across different socioeconomic groups in six countries, Brazil, France, Germany, Indonesia, Italy, and the United Kingdom (UK). The countries were chosen to generate a representative sample across parameters such as per capita income, population size, levels of inequality, dental caries prevalence, structural features of health systems and approaches to oral health.

Methods

A simplified conceptual framework was developed to demonstrate the progression of dental caries from a healthy tooth to an unsalvageable carious tooth that requires extraction. The stages in the progression include the development of an initial white spot lesion caused by demineralisation followed by established more severe stages of dental caries. If left to progress, dental caries can progress to involve the dental pulp (root canal system) and the tooth may eventually become unsalvageable (Fig. 1). The framework also includes interventions for primary prevention at various stages to prevent the development of or limit the progression of caries (secondary prevention). For healthy teeth or those with carious white spot lesions, maintaining good oral hygiene by brushing with fluoridated toothpaste and applying topical fluorides (e.g., fluoride varnish or SDF) or consuming fluoridated products (e.g. fluoridated water or fluoridated salt) are effective preventive measures. Dental fissure sealants effectively prevent caries in healthy teeth or halt the progression of initial carious lesions by sealing the deep grooves and fissures on chewing surfaces, which are prone to decay due to microbial plaque and food accumulation. After established dental caries sets in and forms a cavity, the dental caries process cannot be reversed, and management moves to a "restorative/reparative cycle". Initially, the tooth can be restored using fillings. If the dental caries progresses to compromise the dental pulp, the tooth will require root canal treatment and/or a crown. The most extensive stages of dental caries may result in an unsalvageable tooth, necessitating extraction followed by replacement,

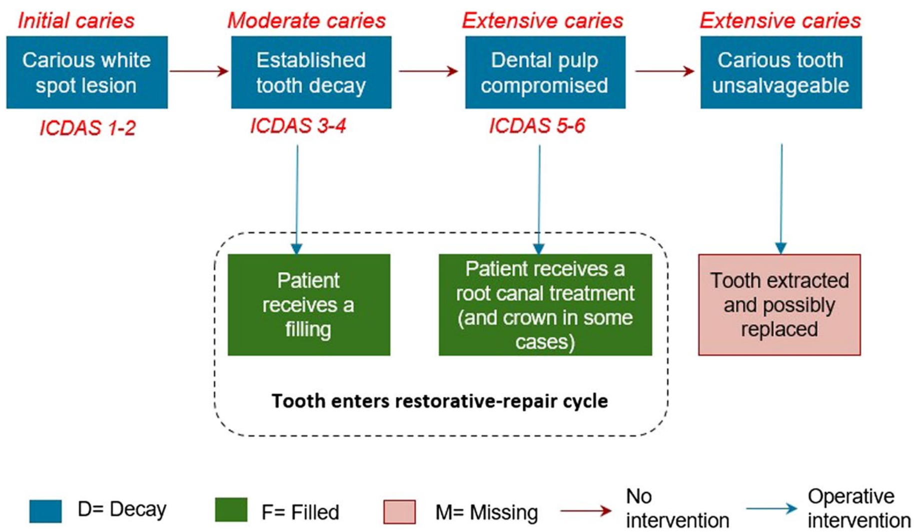

Fig. 2 Framework for analysis

frequently with a dental implant, if affordable, feasible and clinically appropriate.

Based on this conceptual framework, we developed a simplified approach to the dental caries clinical care pathway, based on available data, to enable an estimation of the direct costs of managing dental caries (Fig. 2) [24–26]. We adhered to the Consolidated Health Economic Evaluation Reporting Standards (CHEERS) reporting guidelines to ensure comprehensive and transparent reporting of our analysis [27].

Data inputs

Population data

Data from the World Population Prospects (WPP, 27th edition) was used to determine the population size and age structure for each country, broken down into 5-year age groups [28]. The latest population size estimates for the 10–14 year age group were used as the baseline, and projections were made for the population size as the cohort progressed into the 60–64 year age group, based on general population mortality. The death rate assumptions were derived from the WHO data on probability of dying at a specific age [29]. The formula applied was as follows:

$$Prob\_1yr = 1 - exp(ln\frac{(1 - Prob\_5yr)}{5})$$

where:

Prob_5yr: The probability of dying between 5-year age cohorts.

Prob_1yr: The probability of dying at a specific age.

exp: exponential.

ln: natural logarithm.

Disaggregation by deprivation quintiles

The English Index of Multiple Deprivation IMD 2019 was used to disaggregate the population in each 5-year age cohort into deprivation quintiles. The quintiles were classified as least deprived, second least deprived, middle deprived, second most deprived and most deprived [30]. Following the relative ranking system of the IMD 2019, we assigned 20% of the population in each age cohort into each deprivation group.

Dental caries experience data

We used the commonly used population-based measure of DMFT to quantify the current and past caries experience. DMFT refers to the number of decayed, missing and filled permanent teeth and is calculated as the sum of all decayed, missing and filled teeth among individuals in a specific age group divided by the total population in that age group [31, 32].

DMFT scores for 12-year-olds were sourced from national oral health surveys from Brazil, France, Germany, Indonesia, Italy, and the UK and used as the baseline DMFT to quantify dental caries experience (see Table 1) [33–38]. The UK data is extrapolated from a national survey of England, Wales and Northern Ireland. The total caries experience within the age group was calculated by multiplying the average DMFT scores by the population size in that specific age group. We used separate Welsh and German data among 12-year-olds that showed a similar 0.4 difference in DMFT scores between the least and most deprived groups when stratified by socioeconomic status [37, 39]. This difference of 0.4 between deprivation groups was extrapolated to all the

Table 1 Average number of decayed, filled and missing teeth among 12-year-olds by country

	Decayed teeth (DT)	Filled teeth (FT)	Missing teeth (MT)	Decayed, missing or filled teeth (DMFT)
Brazil	1.12	0.73	0.12	2.07
France	0.5	0.6	0.13	1.23
Germany	0.1	0.3	0.1	0.5
Indonesia	1.8	< 0.1	0.1	1.9
Italy	0.71	0.36	0.02	1.09
UK	0.4	0.3	0.1	0.8

studied countries due to the lack of other country specific data.

The average DMFT data reported in each country's national oral health survey was assumed to apply to the middle-deprived quintile. We derived conversion factors from the Welsh data and adjusted them according to the country's Gini coefficient relative to the UK, which were used to adjust the DMFT scores for the other quintiles (see Table 2) [40].

The calculation used was:

$$DMFT\_1_i = DMFT\_5_i \times \left(\frac{DMFT\_5UK}{DMFT\_1UK}\right) \times \left(\frac{GINI_i}{GINI\_UK}\right)$$

where:

$DMFT\_1_i$ is the DMFT score for the most deprived quintile in country i;

$DMFT\_5i_i$ is the DMFT score for the least deprived quintile in country i;

$DMFT\_1UK$ is the DMFT score for the most deprived quintile in the UK;

$DMFT\_5UK$ is the DMFT score for the least deprived quintile in the UK;

$GINI_i$ is the Gini coefficient for country i;

$GINI\_UK$ is the Gini coefficient for the UK.

Dental caries progression

Data from a large systematic review and meta-analysis reported an unadjusted annual increase in DMFT scores of + 0.18 with a lower progression rate of + 0.07 after adjusting for preventive interventions. The preventive interventions varied across the studies and included school-based preventive education programs, the use of fluoride-containing lozenges, mouthwash, or toothpaste, the application of topical fluorides, or the use of sugar substitutes like xylitol or poly alcohol [41]. Based on these data, an annual increment in DMFT score of + 0.18 was applied to the middle deprivation cohort and that of + 0.07 to the least deprived cohort. We assumed that the least deprived cohort with best access to interventions would have the lowest annual progression rate. Progression rates were then assumed to evolve across income brackets linearly to arrive at the rate of annual progression of DMFT:

- Least deprived quintile: + 0.07
- Second least deprived quintile: + 0.125
- Middle deprived quintile: + 0.18
- Second most deprived quintile: + 0.235
- Most deprived quintile: + 0.29

We assumed that the progression rate in dental caries remains the same across countries and an individual's lifetime, irrespective of the baseline caries experience.

The overall annual progression rate in DMFT was disaggregated across decayed, filled and missing teeth, based on the progression of decayed, filled and missing teeth values reported in The Dunedin Multidisciplinary Health and Development Study [42]. We assumed that the distribution of the values reported in the Dunedin study was representative of the middle-deprived quintile. We then adjusted the distribution of individual DMFT values to other quintiles relative to the middle quintile, employing assumptions related to the likelihood of receiving a filling versus extraction across deprivation groups. For instance, individuals in the most deprived group are more likely to

Table 2 Average DMFT in 12-year-olds by country and income quintile

	Most deprived	Second most deprived	Middle deprived	Second least deprived	Least deprived
	Quintile 1	**Quintile 2**	**Quintile 3**	**Quintile 4**	**Quintile 5**
Brazil	5.37	4.27	2.07	2.07	1.66
France	2.03	1.77	1.23	1.23	0.98
Germany	0.78	0.69	0.50	0.50	0.40
Indonesia	3.53	2.99	1.90	1.90	1.52
Italy	1.88	1.62	1.09	1.09	0.87
UK	1.28	1.12	0.80	0.80	0.64

receive an extraction rather than preventive management or restorative treatments such as fillings, bridges and implants, even in countries with publicly funded dental care, such as the UK [43, 44]. The assumptions used in the distribution of DMFT progression between age cohorts across deprivation quintiles are detailed in Supplementary Table 1 in Supplementary file 1.

Direct costs of managing dental caries

An estimation of the direct costs of managing dental caries was derived through the triangulation of information gathered from country experts and cost data sourced online. The costs associated with dental caries management per tooth are detailed in Supplementary Table 2 in Supplementary file 1. Given the variation in the provision of subsidised care across countries and the lack of information regarding healthcare costs in the public sector, private treatment costs in each country were used as a proxy to estimate the direct costs of dental caries.

An increase in the 'Fillings' component of the DMFT by 1 implies that the patient received a new filling. We assumed the need for re-restoration of a filling every 10 years, based on a conservative estimate of the median survival rate of composite fillings [45, 46]. Of those who received a filling, 9.3% were assumed to have had a root canal treatment, based on data reported in a systematic review [46]. Among patients receiving a root canal treatment, a proportion were assumed to have also received a crown. Both root canal and crown interventions were weighted such that they were more common among the least deprived, owing to the cost of the procedures. The assumptions applied to the provision of root canals and crowns across deprivation groups are detailed in Supplementary Table 3 in Supplementary file 1.

An increase in the 'Missing' component of DMFT by a value of 1 implies that the patient underwent a single tooth extraction. Following extraction, we assumed that less deprived groups were more likely to receive single tooth implants. Besides dental implants, alternative interventions such as dental bridges or single-tooth removable partial dentures can be used to replace a missing tooth. We included an alternative replacement in the analysis in a treatment-agnostic approach to account for various treatment options that were lower cost to a dental implant, and were more likely to occur in the more deprived groups. To provide a credible range for the estimates and to acknowledge the likelihood that not all patients will receive a replacement for a missing tooth, 60% and 30% of the most and second most deprived groups, respectively, do not receive any replacement for a missing tooth in this analysis. The assumptions applied to the provision of replacements across deprivation groups are detailed in Supplementary Table 4 in Supplementary file 1.

Direct costs for dental caries in each age group were calculated as the cost of treatment per tooth multiplied by the number of teeth requiring the treatment multiplied by the percentage of each deprivation group assumed to have the treatment. Based on the UK's National Institute for Health and Care Excellence (NICE) recommendation, a 3.5% discount rate for future costs was applied to the calculation [47].

Scenario analysis

Two scenario analyses were performed to assess the decrease in per capita costs between 12–65 years of age based on the following interventions:

- Scenario 1 – Application of universal interventions with a decrease in caries progression rates by 30% across each deprivation quintile. The 30% decrease in dental caries progression rate was considered conservative, given that the majority of dental caries is preventable via a range of effective public health interventions, such as community water fluoridation, salt fluoridation, reduced sugar consumption (via the implementation of, for example, SSB taxes or enhanced food labelling) and twice daily brushing with fluoridated toothpaste and fluoride varnish (frequency dependent on risk of caries) [48].
- Scenario 2 – A 'levelling-up', or proportionate universalism approach, with the scale of prevention and management interventions proportional to the degree of need across deprivation quintiles. In this scenario, the dental caries progression rate of the least deprived quintile was applied across all quintiles.

Model validation

Consistency checks, face validity assessments and a sensitivity analysis were conducted as part of the model's internal validation. Consistency checks involved amending data and model parameters such as baseline DMFT data, direct costs and probabilities for tooth health transition states were amended to ensure that the model behaves logically, resulting in the expected changes in outcomes. Face validity was ensured by engaging experts in health economics, epidemiology, and oral health experts to review the model to ensure that the assumptions, data inputs, and overall structure were reasonable and reflected current knowledge. We conducted two sensitivity analyses. Sensitivity analysis A involved adjusting the discount rate from 3.5% to 5%, reflecting the upper limit of discount rates applied in a systematic review of modelling techniques for the economic evaluation of dental caries [49]. Sensitivity analysis B involved adjusting treatment costs to provide a range to account for a variation in treatment costs. We estimate overall direct costs if treatment costs were 10% lower and 10% higher versus the treatment costs applied in the primary analysis.

Results

The population-level healthcare costs of managing dental caries for the current cohort of children aged 12 years projected to 65 years varied between a low of US$ 10.2 billion in Italy to a high of US$ 36.2 billion in Brazil (Table 3). Of the countries studied, Indonesia is the most populous followed by Brazil. However, in terms of population-level costs, Indonesia ranked second to Brazil with a cost of US$ 26.2 billion. The cost of all procedures (except implants and alternative replacements) was estimated to be lower in Indonesia than in Brazil, which may explain the lower direct costs of caries at a population-level in Indonesia, compared to Brazil. The largest per-person costs were estimated in the UK, at US$ 22,910, and the lowest per-person costs in Indonesia, at US$ 7,414.

When disaggregated by deprivation quintile, the most deprived group had the highest per person costs in the UK, Italy, Brazil and France (Table 4). In all countries, the most deprived population had the highest baseline caries experience and the highest rate of progression. While we modelled the most deprived to be less likely to receive expensive treatments, such as root canals and implants and more likely to have extractions, they still had the highest direct costs across four of the six countries studied. Of these four countries, Brazil had the greatest difference in costs between the most and the least deprived populations, at US$ 10,555 per person. This can be attributed to Brazil having the higher baseline DMFT value and the greatest inequality among deprivation groups, based on the Gini coefficient. In Germany and Indonesia, the least deprived group had the greatest per-person costs, followed by the most deprived group. Our modelling assumes that the most deprived are more likely to receive just an extraction and a less optimal, lower-cost replacement or no replacement at all, while the least deprived are more likely to get an implant after the extraction. In the UK, Italy, Brazil and France, the cost of an implant is on average 12 to 35 times more expensive than an extraction. However, the ratios are higher in Indonesia and Germany, at 39 and 80 respectively. This may account for the costs in the least deprived being

Table 3 Longitudinal direct costs of caries from 12 to 65 years of age (US$)

	UK	*Germany*	*Italy*	*Indonesia*	*Brazil*	*France*
Least deprived	3,952,882,105	4,392,494,374	2,087,254,583	8,242,443,727	5,749,622,199	3,249,846,230
2nd least deprived	2,249,717,883	1,570,763,442	1,364,257,812	3,022,291,261	4,990,218,141	2,052,293,413
Middle deprived	2,812,794,326	2,019,107,545	1,710,252,438	3,543,124,387	5,828,250,105	2,456,746,619
2nd most deprived	3,858,849,156	2,893,839,532	2,390,523,789	5,511,119,251	8,998,895,492	3,286,358,990
Most deprived	4,259,803,485	3,135,535,744	2,731,728,601	5,955,256,547	10,664,473,762	3,600,994,886
Total	17,134,046,953	14,011,740,637	10,284,017,223	26,274,235,172	36,231,459,699	14,646,240,138
Overall lifetime cost per-person	**22,910**	**21,359**	**20,657**	**7,414**	**15,562**	**21,036**

Economic burden

Lowest

Highest

Table 4 Cost of caries per-person between 12-65 years by deprivation quintile (US$)

	UK	Germany	Italy	Indonesia	Brazil	France
Least deprived	26,427	33,479	20,963	11,629	12,348	23,339
2nd least deprived	15,040	11,972	13,701	4,264	10,717	14,738
Middle deprived	18,805	15,389	17,176	4,999	12,516	17,643
2nd most deprived	25,798	22,057	24,008	7,775	19,326	23,601
Most deprived	28,479	23,899	27,435	8,402	22,903	25,860

Economic burden
Lowest
Highest

higher than in the most deprived in these two countries. Across all countries, the second least deprived population was associated with the lowest estimated costs. This was largely owing to a lower health burden than the middle and more deprived groups, coupled with the assumption that fewer people in this deprivation group (relative to the least deprived group) would receive a single tooth implant to replace a missing tooth.

Table 5 compares the direct costs of dental caries among the most deprived with the average cost of the least and second least deprived groups. Relative to the two least deprived groups, the direct costs range between 5 and 99% higher for the most deprived groups in Germany and Brazil, respectively.

We then modelled the impact of preventive interventions on reducing caries-related direct costs. We conducted a scenario where annual progression rates were reduced by 30%, to account for potential upstream and downstream prevention. The conservative estimate of 30% was intervention-agnostic and applied uniformly to all deprivation groups. With the decrease in progression rates, the greatest reduction in per-person costs for caries management was observed in the most deprived group across all countries except Indonesia, where costs decreased by US$ 1,604 and US$ 1,561 in the least and most deprived groups, respectively.

A 'levelling-up', or proportionate universalism approach, was also applied as a scenario, where preventive and management interventions were proportionate to the degree of need across deprivation quintiles. In this scenario, an annual caries progression rate of + 0.07 that originally pertained to the least deprived group was applied across all quintiles. The per-person reduction in direct costs ranged from US$ 3,948 in Indonesia to US$ 17,728 in the UK (Fig. 3).

The results of sensitivity analysis A, which involved adjusting the discount rate, revealed a similar pattern in costs across deprivation quintiles, with a lower overall cost due to the higher discount rate applied. In sensitivity analysis B, we adjusted treatment costs by ± 10% to account for uncertainty in treatment costs, providing a range in the economic burden across deprivation quintiles in each country. The results of both sensitivity analyses are included in Supplementary file 1.

Discussion

Our study estimated the longitudinal direct costs of caries of permanent teeth occurring in 12-year-olds and how this differs based on socioeconomic status. Despite accounting for the likelihood that more deprived populations receive lower cost and often suboptimal or inappropriate treatment options, such as tooth extraction when

Table 5 Difference in per-person cost of caries for people 12–65 years of age between least and most deprived groups

	UK	Germany	Italy	Indonesia	Brazil	France
Two least deprived groups (averaged) (US$)	20,734	22,726	17,332	7,947	11,533	19,039
Most deprived (US$)	28,479	23,899	27,435	8,402	22,903	25,860
% increase between most deprived and less deprived groups	37	5	58	6	99	36

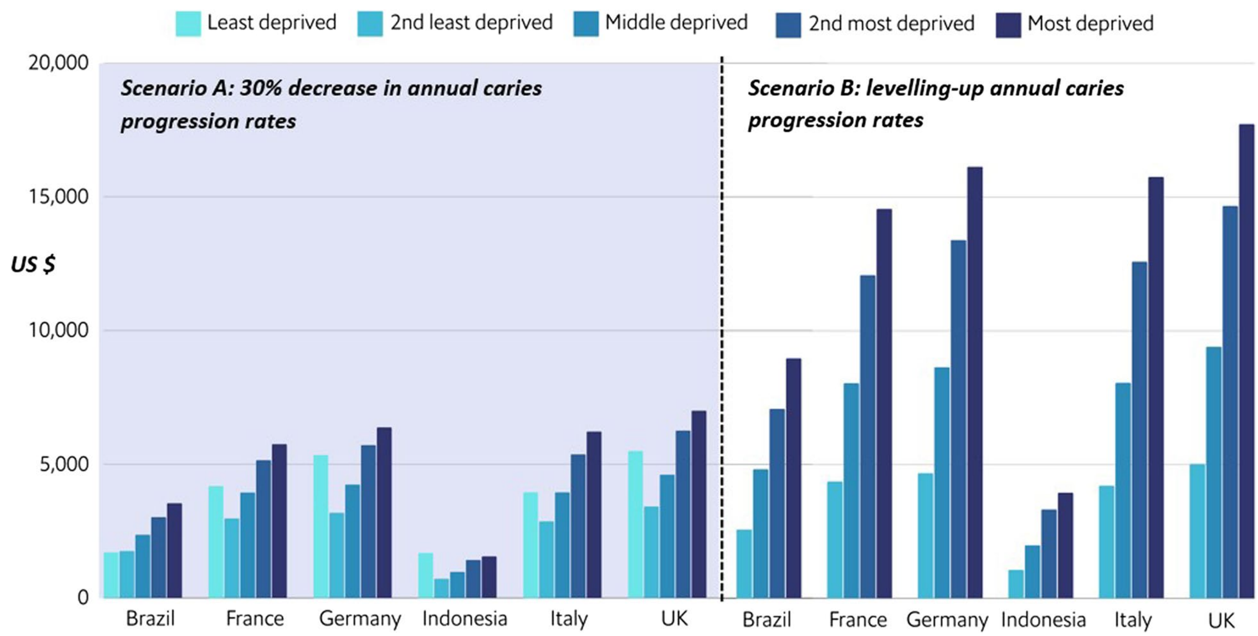

Fig. 3 Decrease in per person costs (US$) after uniform application of non-targeted interventions lowering the progression rate by 30% and a levelling up approach to reduce caries progression

a restorative procedure may be more appropriate, the more deprived populations experience a larger long-term economic burden from dental caries. Studies have shown that individuals who are most deprived are more likely to present to the emergency room with non-traumatic dental issues and to be admitted for caries management [23, 50, 51]. Our study has not considered hospitalisation costs; if they were included, the difference in direct costs between the most and least deprived is likely to widen. Incorporating indirect costs, such as transportation to clinics and economic opportunities, would further increase the gap.

The greater dental caries experience at baseline in the most deprived group is the primary factor leading to an overall higher caries experience and increased direct costs. Therefore, preventive interventions should start early, with a focus on lowering early childhood caries (ECC) and continue through the life course.

A multipronged approach, consisting of upstream and downstream efforts, is needed for effective caries prevention. However, there is a dearth of data on the numerical impact of such a holistic approach in lowering the caries burden. The efficacy of various preventive measures has been studied, mostly in isolation. A systematic review of 107 studies showed that community water fluoridation results in a reduction of dental caries experience by 35% in deciduous teeth and 26% in permanent teeth [10]. Of our study countries, community water fluoridation is performed in Brazil and some parts of the UK [52, 53].

The impact of a SSB tax on lowering dental caries prevalence is less clear, with the majority of evidence derived from modelling studies. A recent umbrella review concluded that a 20% sugar tax would reduce sugar intake by 18% and 20% in low and middle-income and high-income countries, respectively. The review reported that SSB taxes would result in a positive but modest impact on oral health, reducing dental caries prevalence in children by 2.9% and 2.7% for low and middle-income and high-income countries, respectively, reducing caries counts in adults by 0.03, in both low and middle-income and high-income countries [54]. Of our study countries, Brazil, France and the UK, have implemented SSB taxes [55, 56]. The implementation of a SSB tax in the UK has shown a 12.1% relative reduction in hospital admission for carious tooth extractions, but more work needs to be done in estimating the changes in dental caries prevalence [57]. There are only a few studies evaluating the impact of school-based oral health education programmes in reducing dental caries experience. Most failed to show a significant reduction in dental caries unless combined with fluoride mouth rinses and application of topical fluorides [58]. SDF, which was recently added to WHO's Essential Medicine, is a low-cost dental caries treatment option that has demonstrated high efficacy in a range of community health and outreach programs, including among children in school settings, Aboriginal children living in remote areas in Australia, residents and older adults in nursing homes and long-term care facilities [59]. While SDF may cause black staining of treated areas, which may be a concern for visible teeth, its advantages in terms of cost, accessibility, ease of application, and effectiveness in managing dental caries make it a highly suitable option for dental care, particularly in resource-limited settings [60, 61].

At an individual level, tooth brushing with fluoride toothpaste has shown standalone benefit in reducing caries prevalence, while other strategies, such as the application of fluoride varnish, do not appear effective in isolation to reduce dental caries progression [62]. A Cochrane systematic review evaluating the impact of tooth brushing showed a 24% reduction in dental caries experience as measured by DFMS scores among children using fluoridated toothpaste versus those using non-fluoridated toothpaste [63].

Given the lack of data regarding the decrease in progression rates using a multipronged approach, we assumed a 30% reduction based on diverse literature. With this decrease applied uniformly to all deprivation groups, the most deprived group showed the greatest reduction in costs across all countries, with the exception of Indonesia, where the most deprived group was a close second to the least deprived. A levelling-up approach to prevention resulted in a greater reduction of dental caries progression in the most deprived group and lowered direct costs dramatically for the most deprived.

It should be noted that the most deprived face additional challenges in implementing effective home care strategies to prevent dental caries, especially in times of a cost-of-living crisis. A survey conducted in 2022 by the Oral Health Foundation reported that one in four people in the UK were cutting back on oral health products, such as toothpaste and mouthwash, due to economic challenges [64]. Even when accessing toothpaste, more deprived populations may not be accessing an effective product. A recent study from Manaus, Brazil, found that cheaper formulations of fluoride toothpaste, which are more commonly used by more deprived populations, lacked a sufficient total fluoride concentration to control dental caries in 92% of the 99 toothpaste tubes tested [17].

The limitations of our model mainly hinge on challenges in identifying suitable data inputs. National oral health surveys were used to identify the baseline DMFT scores, but these were collected across a range of years (2007–2018). The data does not accurately reflect recent trends and the covid-19 pandemic-related setbacks in oral care. Moreover, the prevalence of dental caries segregated by deprivation quintile was not available for every country studied. Annual rates of dental caries progression across deprivation quintiles have not been extensively documented. Therefore, extrapolations and assumptions had to be made. Studies have shown that the most deprived patients are less likely to get fillings, root canal treatments, or implants but the exact differences in the rates of these treatments between deprivation groups are not known [43, 44]. Additionally, there is a lack of documentation of health care system costs for caries care in the public sector. Costs from the private sector were used based on triangulation of online data sources and expert input, but there is significant variability in the costs resulting in a wide range of estimates. The probabilities for tooth health transition states were informed by data from a single cohort study in New Zealand and applied across our study countries. This was necessary due to the lack of longitudinal data of this nature, however, it represents a limitation as tooth health transition states may vary across countries.

Our study has used DMFT scores to quantify the health and economic burden of dental caries as the DMFT Index is the most common method used for assessing and measuring dental caries in epidemiology studies. However, dental science and understanding of oral health have advanced significantly since the Index was developed in 1938. Limitations of the Index include its inability to distinguish between active (progressing) and restored caries and that it typically excludes pre-cavitation stages from the measurement of the caries lesion, which is key for a more modern and preventive approach to dental caries. This also means that our analysis will have underestimated some direct treatment costs as we did not account for the costs of managing initial caries. A further limitation of the DMFT Index is that it doesn't capture the impact of dental caries on quality of life or outcomes that matter to people living with dental caries. Experts in the field have been calling for alternative lesion detection thresholds and outcome measures to be used in population oral health [65].

The complete benefit of preventive measures on caries progression can only be estimated by including early, reversible carious lesions. Measures such as the International Caries Detection and Assessment System (ICDAS), the American Dental Association Caries Classification System (ADA CCS), Caries Assessment Spectrum and Treatment (CAST), and Nyvad's Criteria each facilitate the detection of dental caries across the entire disease continuum, and their wider use would provide a better estimation of early caries and the cost savings of preventive measures [66–68]. It is encouraging that the FDI World Dental Federation, having started to promote Minimal Intervention in the Management of Dental Caries in 2002, issued a new Policy Statement in 2019 on Carious Lesions and First Restorative Treatment [69]. This states that: "*FDI World Dental Federation supports a shift in caries management from restorative treatment* *to measures that arrest and prevent caries development including monitoring, following the concepts of International Caries Classification and Management System (ICCMS)".* Linking of these epidemiological and outcome measures to quality of life metrics would also be of value.

Future studies on the relative costs and benefits of a population approach to oral health and equity should consider collecting the following data for epidemiological and health service research:

- Transparent cost data for publicly funded dental treatment by country (and sub-national or community level)
- Population-level, cross-sectional, data at a country level of the proportion of people paying out-of-pocket for dental care, paying for private treatment through insurance premiums, and receiving publicly funded dental care through social/worker Insurance or universal coverage. Including mixed schemes or partial charges.
- Longitudinal cohort data on the progression of dental caries within populations covered by different types of funding schemes.
- New epidemiological and outcome measures for oral health. Metrics that do not weigh a decayed tooth and a filled tooth equally (such as DMFT). Ideally, measures that are:
    - Easy to collect by survey and by health practitioners
    - Collected (with age-appropriate variations) for all groups across the life course, from preschool children to the elderly
    - Consider unrestored dental caries, overall dental caries experience, preventive and operative treatments received and treatment urgency
    - Validated against quality of life metrics

Conclusion

For several decades, the cornerstone of dental caries management in dental practice has been a reparative/restoratively driven approach that results in significant morbidity and huge costs. This is in stark contrast to preventive models of care that are universally taught at the undergraduate level, and there is increasing emphasis on a more sustainable model of preventive management. Strong data regarding the health and economic benefits of this preventive approach is key to galvanising the support of policymakers.

This exploratory modelling study highlights the impact of caries burden, and how the greatest health burden and direct costs of caries are seen in the most deprived populations. A multipronged preventive approach, if instituted, will offer maximum reductions in direct costs to the most deprived, and highlights a strong case for "levelling-up" preventive actions focused on this segment of the population.

Several data gaps remain to be filled to ensure a more accurate estimation of the value, costs and associated savings of such an approach. Epidemiological measures that include early/reversible caries lesions should continue to be made more user-friendly to facilitate widespread incorporation into such assessments, thereby improving the estimates of benefits offered by preventive care.

The results of this analysis support the case for a more inclusive public health approach to caries management, that incentivises and focuses on prevention and early minimally interventive treatment to improve population-level oral health. Transformative changes in oral healthcare funding models are required to realise the financial benefits of preventive and minimal intervention approaches, and for levelling up oral/dental health to reduce inequalities across socioeconomic groups.

Abbreviations

ADA CCS	American Dental Association Caries Classification System
CAST	Caries Assessment Spectrum and Treatment
DMFT	Decayed, Missing or Filled Teeth
DT	Decayed teeth
ECC	Early childhood caries
FT	Filled teeth
GBD	The Global Burden of Disease
ICCMS	International Caries Classification and Management System
ICDAS	International Caries Detection and Assessment System
IMD	English Index of Multiple Deprivation
MT	Missing teeth
NICE	National Institute for Health and Care Excellence
SDI	Social Development Index (SDI)
UK	United Kingdom
WHO	World Health Organization
WPP	World Population Prospects

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12889-024-20652-0.

Supplementary Material 1

Acknowledgements
Not applicable.

Authors' contributions
G.D, N.V., and R.R wrote the main manuscript text. G.D, N.V, J.H. prepared the figures. J.H. prepared the tables. N.W. was responsible for the overall strategy, conception and initiation of this research. N.P. outlined the conceptual framework of modern, evidence-based approaches to caries management which was integrated with the new cohort simulation model. I.C. contributed to the overall strategy and concept and critical appraisal of the manuscript. S.J., N.V., G.D. and R.C. developed the analysis framework. G.D, N.V, J.H. collected the data inputs and performed the analysis. M.V. and K.B. reviewed and provided critical feedback on each draft of the manuscript. All authors read and approved the final manuscript.

Funding
The study was supported by a grant from Haleon.

Data availability
The data related to the assumptions used in the analysis are available in Additional file 1. The dataset generated during this analysis is available from the corresponding author upon reasonable request.

Declarations

Ethics approval and consent to participate
Not applicable.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

Author details
[1]Economist Impact, London, UK. [2]Department of Medicine, Division of Haematology, Medical Oncology & Haematopoietic Stem Cell Transplantation, The University of Hong Kong, Hong Kong, Hong Kong. [3]Health Policy Institute, American Dental Association, Chicago, USA. [4]Birmingham NIHR Biomedical Research Centre, The University of Birmingham, Birmingham, UK. [5]Division of Periodontics, Section of Oral, Diagnostic and Rehabilitation Sciences, Columbia College of Dental Medicine, Columbia University, New York, NY, USA. [6]Division of Periodontology and Oral Rehabilitation, Dentistry, School of Health Sciences, College of Medicine and Health, University of Birmingham, Birmingham, UK. [7]Birmingham Community Healthcare NHS Trust, Birmingham, UK. [8]Periodontal Research Group, Dentistry, School of Health Sciences, College of Medicine and Health, University of Birmingham, Birmingham, UK. [9]Periodontology, Bristol Dental School, University of Bristol, Bristol, UK. [10]Faculty of Dentistry, Oral & Craniofacial Sciences, King's College London, London, UK.

Received: 12 February 2024 Accepted: 6 November 2024
Published online: 21 November 2024

References

1. WHO. Global oral health status report: towards universal health coverage for oral health by 2030. Geneva: World Health Organization, 2022. Available from: https://www.who.int/publications/i/item/9789240061484.
2. Wen PYF, Chen MX, Zhong YJ, Dong QQ, Wong HM. Global Burden and Inequality of Dental Caries, 1990 to 2019. J Dent Res. 2022;101(4):392–9.
3. WHO. Sugars and dental caries. Geneva: World Health Organization, November 2017. Available from: https://www.who.int/news-room/fact-sheets/detail/sugars-and-dental-caries
4. WHO. Oral health. Geneva: World Health Organization, March 2023. Available from: https://www.who.int/news-room/fact-sheets/detail/oral-health
5. Costa SM, Martins CC, Bonfim MdLC, Zina LG, Paiva SM, Pordeus IA, et al. A systematic review of socioeconomic indicators and dental caries in adults. Int J Environ Res Public Health. 2012;9(10):3540–74.
6. Kazmi A, Ismail M, Kazmi N. Why do children still have preventable caries? BDJ Team. 2021;8(2):10–1.
7. WHO. Commercial determinants of health. Geneva: World Health Organization, March 2023. Available at: https://www.who.int/news-room/fact-sheets/detail/commercial-determinants-of-health
8. Foley M, Akers H. Does poverty cause dental caries? Aust Dent J. 2019;64(1):96–102.
9. UK Government. The impact of COVID-19 on access to dental care: a report from the 2021 Adult Oral Health Survey. London: United Kingdom Government, 2023. Available from: https://www.gov.uk/government/statistics/the-impact-of-covid-19-on-access-to-dental-care/the-impact-of-covid-19-on-access-to-dental-care-a-report-from-the-2021-adult-oral-health-survey#:~:text=Just%20over%20a%20third%20(35,(COVID%2D19)%20pandemic
10. Iheozor-Ejiofor Z, Worthington HV, Walsh T, O'Malley L, Clarkson JE, Macey R, et al. Water fluoridation for the prevention of dental caries. Cochrane Database Syst Rev. 2015;2015(6):Cd010856.
11. Mariño R, Zaror C. Economic evaluations in water-fluoridation: a scoping review. BMC Oral Health. 2020;20(1):115.
12. Sanders AE, Grider WB, Maas WR, Curiel JA, Slade GD. Association Between Water Fluoridation and Income-Related Dental Caries of US Children and Adolescents. JAMA Pediatr. 2019;173(3):288–90.
13. Hernández FM, Cantoral A, Colchero MA. Taxes to Unhealthy Food and Beverages and Oral Health in Mexico: An Observational Study. Caries Res. 2021;55(3):183–92.
14. Petimar J, Gibson LA, Wolff MS, Mitra N, Corby P, Hettinger G, et al. Changes in Dental Outcomes After Implementation of the Philadelphia Beverage Tax. Am J Prev Med. 2023;65(2):221–9.
15. WHO. Global report on the use of sugar-sweetened beverage taxes 2023. Geneva: World Health Organization, 2023. Available from: https://iris.who.int/bitstream/handle/10665/374530/9789240084995-eng.pdf?sequence=1
16. Moynihan P. Sugars and Dental Caries: Evidence for Setting a Recommended Threshold for Intake. Adv Nutr. 2016;7(1):149–56.
17. Ramos MCC, Rebelo MAB, Rebelo Vieira JM, Miranda LFB, Tabchoury CPM, Cury JA. Fluoride toothpaste, sanitary surveillance and the SUS: the case of Manaus-AM. Brazil Rev Saude Publica. 2022;56:9.
18. Baik A, Alamoudi N, El-Housseiny A, Altuwirqi A. Fluoride varnishes for preventing occlusal dental caries: A review. Dentistry journal. 2021;9(6):64.
19. Contreras V, Toro MJ, Elías-Boneta AR, Encarnación-Burgos A. Effectiveness of silver diamine fluoride in caries prevention and arrest: a systematic literature review. Gen Dent. 2017;65(3):22–9.
20. UK Government. Inequalities in oral health in England: Summary. London: United Kingdom Government, 2021. Available from: https://www.gov.uk/government/publications/inequalities-in-oral-health-in-england/inequalities-in-oral-health-in-england-summary
21. ACFF. An Economic perspective of the global burden of dental caries. Scotland: The Alliance for a Cavity Free Future. Available from: https://www.acffglobal.org/wp-content/uploads/2021/03/An-economic-perspective-on-the-burden-of-dental-caries.pdf
22. Righolt AJ, Jevdjevic M, Marcenes W, Listl S. Global-, Regional-, and Country-Level Economic Impacts of Dental Diseases in 2015. J Dent Res. 2018;97(5):501–7.
23. UK Government. Hospital tooth extractions in 0 to 19 year olds 2022. London: GOV.UK, 2023. Available from: https://www.gov.uk/government/statistics/hospital-tooth-extractions-in-0-to-19-year-olds-2022/hospital-tooth-extractions-in-0-to-19-year-olds-2022
24. Pitts NB, Ekstrand KR. International Caries Detection and Assessment System (ICDAS) and its International Caries Classification and Management System (ICCMS) - methods for staging of the caries process and enabling dentists to manage caries. Community Dent Oral Epidemiol. 2013;41(1):e41-52.
25. Sicca C, Bobbio E, Quartuccio N, Nicolò G, Cistaro A. Prevention of dental caries: A review of effective treatments. J Clin Exp Dent. 2016;8(5):e604–10.
26. Ismail AI, Sohn W, Tellez M, Amaya A, Sen A, Hasson H, et al. The International Caries Detection and Assessment System (ICDAS): an integrated system for measuring dental caries. Community Dent Oral Epidemiol. 2007;35(3):170–8.
27. Husereau D, Drummond M, Augustovski F, de Bekker-Grob E, Briggs AH, Carswell C, et al. Consolidated Health Economic Evaluation Reporting Standards (CHEERS) 2022 Explanation and Elaboration: A Report of the ISPOR CHEERS II Good Practices Task Force. Value Health. 2022;25(1):10–31.
28. UNDESA. World Population Prospects 2022. New York: United Nations Department of Economic and Social Affairs, 2022. Available from: https://population.un.org/wpp/
29. WHO. Nqx-probability of dying between ages x and x+n (GHE: life tables). Geneva: World Health Organization Global Health Observatory. Available from: https://www.who.int/data/gho/data/indicators/indicator-details/GHO/gho-ghe-life-tables-nqx-probability-of-dying-between-ages-x-and-x-n
30. Ministry of Housing, Communities and Local Government. The English Indices of Deprivation 2019 (IoD 2019). London: Ministry of Housing,

Communities and Local Government. Available from: https://assets.publishing.service.gov.uk/media/5d8e26f6ed915d5570c6cc55/IoD2019_Statistical_Release.pdf
31. Shulman JD, Cappelli DP. Chapter 1 - Epidemiology of Dental Caries. In: Cappelli DP, Mobley CC, editors. Prevention in Clinical Oral Health Care. Saint Louis: Mosby; 2008. p. 2–13.
32. WHO. Mean number of Decayed, Missing and Filled permanent teeth (mean DFMT) among the 12-year-old age group. Geneva: World Health Organization The Global Health Observatory. Available from: https://www.who.int/data/gho/indicator-metadata-registry/imr-details/3812
33. Agency for Health Research and Development. National Riskesdas Report 2018. Jakarta: Agency for Health Research and Development, 2019. Available from: https://repository.badankebijakan.kemkes.go.id/id/eprint/3514/1/Laporan%20Riskesdas%202018%20Nasional.pdf
34. MHB. Pesquisa Nacional de Saúde Bucal Resultados Principais. Brasilia: Ministry of Health of Brazil, 2010. Available from: https://bvsms.saude.gov.br/bvs/publicacoes/pesquisa_nacional_saude_bucal.pdf
35. HAS. Stratégies de prévention de la carie dentaire. Paris: Haute Autorité de Santé, 2010. Available from: https://www.has-sante.fr/upload/docs/application/pdf/2010-10/corriges_rapport_cariedentaire_version_postcollege-10sept2010.pdf
36. Campus G, Solinas G, Cagetti MG, Senna A, Minelli L, Majori S, et al. National Pathfinder survey of 12-year-old Children's Oral Health in Italy. Caries Res. 2007;41(6):512–7.
37. Jordan R, Micheelis W. The Fifth German Oral Health Study (DMS V). Series of materials. Band 35. Institut der Deutschen Zahnärzte. Köln, Deutscher Zahnärzte Verlag DÄV. 2016.
38. NHS. Child Dental Health Survey 2013, England, Wales and Northern Ireland. Wales: National Health Service, 2015. Available from: https://digital.nhs.uk/data-and-information/publications/statistical/children-s-dental-health-survey/child-dental-health-survey-2013-england-wales-and-northern-ireland
39. Morgan M, Monaghan N. Picture of Oral Health 2018. Dental epidemiological survey of 12-year-olds 2016–2017. Cardiff University, 2018. Available from: https://www.cardiff.ac.uk/__data/assets/pdf_file/0019/1201465/Full-Report-Oral-Health-2018.pdf
40. World Bank. Gini Index. Washington, D.C.: World Bank, 2023. Available from: https://data.worldbank.org/indicator/SI.POV.GINI
41. Hummel R, Akveld N, Bruers J, Van der Sanden W, Su N, Van Der Heijden G. Caries progression rates revisited: a systematic review. J Dent Res. 2019;98(7):746–54.
42. Hong CL, Broadbent JM, Thomson WM, Poulton R. The Dunedin Multidisciplinary Health and Development Study: oral health findings and their implications. J R Soc N Z. 2020;50(1):35–46.
43. Wanyonyi KL, Radford DR, Gallagher JE. Dental treatment in a state-funded primary dental care facility: contextual and individual predictors of treatment need? PLoS ONE. 2017;12(1): e0169004.
44. Cheema J, Sabbah W. Inequalities in preventive and restorative dental services in England, Wales and Northern Ireland. Br Dent J. 2016;221(5):235–9.
45. Fernandes N, Vally Z, Sykes L. The longevity of restorations -A literature review. South African Dental Journal. 2015;70:410–3.
46. León-López M, Cabanillas-Balsera D, Martín-González J, Montero-Miralles P, Saúco-Márquez JJ, Segura-Egea JJ. Prevalence of root canal treatment worldwide: a systematic review and meta-analysis. Int Endod J. 2022;55(11):1105–27.
47. National Institute for Health and Care Excellence. NICE health technology evaluations: the manual. London: National Institute for Health and Care Excellence, 2022. Available from: https://www.nice.org.uk/process/pmg36/chapter/economic-evaluation
48. Horst JA, Tanzer JM, Milgrom PM. Fluorides and other preventive strategies for tooth decay. Dental Clinics. 2018;62(2):207–34.
49. Qu Z, Zhang S, Krauth C, Liu X. A systematic review of decision analytic modeling techniques for the economic evaluation of dental caries interventions. PLoS ONE. 2019;14(5): e0216921.
50. Akinlotan MA, Ferdinand AO. Emergency department visits for nontraumatic dental conditions: a systematic literature review. J Public Health Dent. 2020;80(4):313–26.
51. Kruger E, Tennant M. Socioeconomic disadvantage and oral-health-related hospital admissions: a 10-year analysis. BDJ Open. 2016;2(1):16004.
52. Aurélio Peres M, Simara Fernandes L, Glazer PK. Inequality of water fluoridation in Southern Brazil–the inverse equity hypothesis revisited. Soc Sci Med. 2004;58(6):1181–9.
53. National Health Service England. Fluoride. London: National Health Service, 2022. Available from: https://www.nhs.uk/conditions/fluoride/.
54. Hajishafiee M, Kapellas K, Listl S, Pattamatta M, Gkekas A, Moynihan P. Effect of sugar-sweetened beverage taxation on sugars intake and dental caries: an umbrella review of a global perspective. BMC Public Health. 2023;23(1):986.
55. Bridge G, Groisman S, Bedi R. Sugar-sweetened beverage taxes in Brazil: past, present, and future. J Public Health Policy. 2022;43(2):281–91.
56. Sarda B, Debras C, Chazelas E, Péneau S, Le Bodo Y, Hercberg S, et al. Public perception of the tax on sweetened beverages in France. Public Health Nutr. 2022;25(11):3240–51.
57. Rogers NT, Conway DI, Mytton O, Roberts CH, Rutter H, Sherriff A, et al. Estimated impact of the UK soft drinks industry levy on childhood hospital admissions for carious tooth extractions: interrupted time series analysis. BMJ Nutrition, Prevention & Health. 2023;6(2):243–52.
58. Ruff RR, Monse B, Duijster D, Itchon GS, Naliponguit E, Benzian H. Effectiveness of school-based strategies to prevent tooth decay in Filipino children: A cluster-randomized trial. Community Dent Oral Epidemiol. 2023;51(2):219–27.
59. WHO. Model List of Essential Medicines. Geneva: World Health Organization, 2021. Available from: https://apps.who.int/iris/bitstream/handle/10665/345533/WHO-MHP-HPS-EML-2021.02-eng.pdf
60. Bridge G, Martel AS, Lomazzi M. Silver Diamine Fluoride: Transforming Community Dental Caries Program. Int Dent J. 2021;71(6):458–61.
61. Subbiah GK, Gopinathan NM. Is Silver Diamine Fluoride Effective in Preventing and Arresting Caries in Elderly Adults? A Systematic Review. J Int Soc Prev Community Dent. 2018;8(3):191–9.
62. Amend S, Hartmann T, Heinzel-Gutenbrunner M, Frankenberger R, Krämer N, Winter J. Caries Experience and Increment in Children Attending Kindergartens with an Early Childhood Caries Preventive Program Compared to Basic Prophylaxis Measures—A Retrospective Cohort Study. J Clin Med. 2022;11(10):2864.
63. Marinho VC, Higgins JP, Sheiham A, Logan S. Fluoride toothpastes for preventing dental caries in children and adolescents. Cochrane Database Syst Rev. 2003;2003(1):Cd002278.
64. Carter N. Cost of living could signal an oral health decline. Word of Mouth Issue 94. September 2022:8–10. https://www.dentalhealth.org/Handlers/Download.ashx?IDMF=e319adaa-6fda-4.
65. Nguyen TM, Rogers H, Taylor GD, Tonmukayakul U, Lin C, Hall M, et al. Fit for Purpose? The Suitability of Oral Health Outcome Measures to Inform Policy. JDR Clin Trans Res. 2024;9(2):190–2.
66. Pitts NB, Banerjee A, Mazevet ME, Goffin G, Martignon S. From "ICDAS" to "CariesCare International": the 20-year journey building international consensus to take caries evidence into clinical practice. Br Dent J. 2021;231(12):769–74.
67. Nyvad B, Machiulskiene V, Baelum V. Reliability of a new caries diagnostic system differentiating between active and inactive caries lesions. Caries Res. 1999;33(4):252–60.
68. Campus G, Cocco F, Ottolenghi L, Cagetti MG. Comparison of ICDAS, CAST, Nyvad's Criteria, and WHO-DMFT for Caries Detection in a Sample of Italian Schoolchildren. Int J Environ Res Public Health. 2019;16(21):4120.
69. FDI. Carious Lesions and First Restorative Treatment. San Francisco: World Dental Federation. Available from: https://www.fdiworlddental.org/carious-lesions-and-first-restorative-treatment

Publisher's Note