



**ECONOMIST
IMPACT**

**Time to put your
money where
your mouth is**

Addressing inequalities in oral health

COMMISSIONED BY



EFP

European Federation
of Periodontology

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Contents

3	About this report
6	Executive summary
15	Introduction
19	The scale of the problem
20	Socioeconomic, cultural and commercial determinants of oral health
22	Impact of oral health challenges on well-being widens the gap further
24	Access to dental care: a challenge, especially for the deprived
26	Preventive care in oral health: a pressing need
30	Caries prevention and care cost calculator
33	The cost of inaction in caries
36	Towards levelling the playing field
45	Conclusion
47	Appendix I: Methods
55	Appendix II: References

About this report

Time to put your money where your mouth is: addressing inequalities in oral health is an Economist Impact white paper, commissioned by the European Federation of Periodontology (EFP) and supported by Haleon.

There have been few efforts thus far to study periodontitis and caries together in a holistic fashion. This report provides an independent analysis of the growing burden of periodontitis and caries, the linkages between these diseases and examines how an integrated approach can mitigate common risk factors, improve individual oral health outcomes and promote wider systemic health.

As part of this work, we developed the “caries prevention and care cost calculator” that estimates the longitudinal direct costs of caries management across different socioeconomic groups in six countries (Brazil, France, Germany, Italy, Indonesia and the United Kingdom) and the cost reduction associated with applying preventive interventions either uniformly or using a levelling-up approach. A literature review followed by consultations with experts through a group meeting and one-on-one interviews informed our report and economic analysis.

This research adds to our previous work in gum disease, *“Time to take gum disease seriously”*, which demonstrated a positive return on investment (ROI) for home-based preventive care and earlier diagnosis and management of periodontitis across six European countries.

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Executive summary

Oral diseases have surpassed all other non-communicable diseases (NCDs) in terms of their global prevalence. The most common oral diseases are caries and severe periodontitis,ⁱ affecting about 2bn and 1bn people, respectively.¹ Furthermore, these two highly prevalent diseases have a disproportionate impact on countries and populations with lower socioeconomic status. Socioeconomic deprivation is associated with lower awareness of oral self-care measures, increased intake of sugary foods and drinks that propagate these conditions, higher malnutrition rates and lower access to individual-level preventive measures and products such as toothbrushes, dental floss, interdental brushes, and fluoridated toothpaste or professionally applied fluoride varnish. These vulnerable populations also suffer poor access to treatment.²

This report, commissioned by the EFP and sponsored by Haleon, is a novel effort to look at both periodontitis and caries in an integrated fashion. The report examines the inequalities in oral health, the factors contributing to this unequal burden, and the opportunities available to level up oral health. It draws on substantial desk research and consultations with 17 experts, which occurred through discussions within an advisory board or through in-depth interviews.



ⁱ Severe periodontitis affects 19% of adults. However, the term “gum disease” encompasses “gingivitis” impacting up to 90% of adults, “periodontitis”, impacting 45-50% of adults.



Our previous white paper on the economic burden of “gum disease” and the benefits of preventive care highlighted that the highest impact was on those with the greatest social deprivation. The modelling employed was specific to periodontal disease. However, there are also deficiencies in our understanding of the longitudinal health and economic impact of dental caries. While it’s known that people in lower socioeconomic groups experience the greatest health burden from caries, the disparities in the economic impact between different socioeconomic groups are not well studied. The extent of gains that can be achieved with effective upstream and downstream preventive measures also remains unclear. A better understanding of the health and cost implications could mobilise policy efforts to expand the application of preventive interventions and mitigate inequities. Therefore, we developed the “caries prevention

and care cost” calculator. This calculator aims to: 1) determine the longitudinal direct costs of management of dental caries between the ages of 12 and 65 years across different socioeconomic groups and 2) the potential reduction in these costs from oral health-promoting interventions. Six countries were included in the assessment: Brazil, France, Germany, Indonesia, Italy, and the United Kingdom (UK). Due to lack of information regarding healthcare system costs in the public sector, private sector costs were used to estimate the burden.

Based on our past work on periodontal diseases, the results of our “caries prevention and care cost calculator”, and insights gathered from the experts, we analysed the overall gaps in the oral health care space and identified opportunities to provide holistic care with a focus on disease prevention.

Key findings

Mainstream framing of oral diseases as NCDs is lacking

There has been a monumental shift in our understanding of periodontal disease and caries – they are no longer viewed as communicable diseases that are caused by microbes. We now understand that a beneficial balance of microbes is seen in the mouths of healthy individuals.³ Excessive intake of sugary foods promote the growth of acid-loving or acid-tolerating (cariogenic) bacteria in dental plaque. These bacteria metabolise the sugars and other fermentable carbohydrates, producing acids that damage tooth surfaces and cause caries.⁴ Gingivitis (inflammation of the gums) drives the emergence of disease-forming microbes, which, in susceptible people, then leads to periodontitis.⁵ Individual susceptibility is governed by several risk factors, some of which are shared with other NCDs. Therefore, periodontitis and caries are now classified as NCDs that are largely preventable. In 2021, the World Health Organization (WHO) adopted a Resolution on oral health, which recommended pivoting to a preventive approach for oral diseases and integrating oral care with NCDs care into the universal health care (UHC) agenda.⁶ Yet, the current mainstream framing of NCDs that prioritises five NCDs (mental disorders, cardiovascular diseases, diabetes, cancers and chronic respiratory diseases), and their risk factors, pays no attention to oral diseases or their main risk factor – simple/refined sugars.⁷

Barriers exist to implementing upstream and downstream preventive measures

At the population-level, community water fluoridation, the use of sugar taxes and community or school-based oral health education programmes are effective measures for lowering oral disease burden.^{8,9} At the individual-level, tooth brushing (that effectively removes plaque) twice a day with a toothpaste containing 1000-1500ppm of fluoride, as well as daily interdental cleaning (cleaning between teeth), prevent or delay development and progression of caries and periodontal diseases. The application of regular fluoride varnish or the use of sealants prevents/delays caries, while smoking cessation and controlling blood glucose improves periodontitis outcomes.^{10,11,12,13} However, there remain several barriers to the implementation of these measures.



While community water fluoridation is practised in Brazil and certain regions of the UK, other countries like Germany, France and Indonesia do not utilise this measure.¹⁴ A combination of factors such as the lack of political will, geographical difficulties due to the diversity of terrain and people using alternate sources such as well water for drinking pose challenges to fluoridation of water. France was one of the first European countries to introduce a sugar tax.¹⁵ The UK introduced a Soft Drinks Industrial Levy in 2018.¹⁶ Brazil introduced a tax on Sugar-Sweetened Beverages (SSB) in 2013, but contrary to global trends, the Brazilian government lowered the SSB tax rates in 2016 and 2018.¹⁷ Italy proposed a sugar tax in 2020, but strong opposition from corporate players has delayed its implementation.¹⁸ School-based preventive health programmes are commonplace in our countries of study, but they have been impacted by school closures during the pandemic.¹⁹ There is a push to start oral health education much earlier, as early as during pregnancy, as part of a true life-course approach to improve oral health. But more needs to be done in this regard.²⁰

Interdental cleaning, adjunctive to toothbrushing, is the most effective method to reduce plaque and improve periodontal health, but studies have shown lower levels of interdental cleaning among people of lower socioeconomic status due to lack of access and awareness.^{21,22} Evidence shows that individuals from lower socioeconomic groups are unlikely to use oral hygiene aids like mouthwash, interproximal brushes, and various medicated toothpastes because of their high cost.²³ The use of fluoridated toothpaste is a simple and easy measure to lower the risk of caries. However, a lack of standardisation of the fluoride content of various toothpastes, misinformation on the safety of fluoride use, and the cost-of-living crisis that is affecting purchasing power for oral health products are important barriers to its use.^{24,25}

Clinical care for dental caries remains largely focused on a “repair approach”

Decades of oral care have focused on a restorative-reparative approach for what we understand now to be a largely preventable disease. Oral health professionals lack training in preventive care and their remuneration continues to perversely incentivise a surgical approach, giving birth to the phrase “drilling, filling and billing”. Besides remuneration models, workforce limitations also pose challenges to the preventive approach. Currently, only ~23% of the global population is estimated to have access to oral health services. Access is particularly poor in low-income countries and populations, as well as in rural areas.^{26,27} Many adults, especially in lower socioeconomic groups, never see a dentist in their lifetime, except for emergency care. While there are several allied health professionals such as dental therapists, hygienists and dental nurses with enhanced skills who can expand coverage, they are not uniformly recognised as formal members of the dental care workforce in many countries.



The most deprived bear the highest costs of inadequate preventive efforts

In our modelling study, at the population-level, the overall direct costs of caries, in people aged 12-65 years, varied from \$10,284bn in Italy to \$36,231bn in Brazil; the difference is partly explained by differences in population sizes. The largest per-person costs were estimated in the UK at \$22,910 and the lowest in Indonesia at \$7,414. A disproportionately high burden of direct costs was seen among the most deprived populations across Brazil, France, Italy and the UK. More deprived populations often experience suboptimal or inappropriate treatment options due to their inability to afford better options; for example, undergoing a tooth extraction when a restorative procedure may be more appropriate or receiving a lower-cost replacement tooth or foregoing any replacement. Despite accounting for this in the model, the more deprived populations were still estimated to experience a larger economic burden from dental caries than the other deprivation groups. In Germany and Indonesia, the per-person costs were highest in the least deprived, followed closely by the most deprived, which is likely explained by the high cost of dental implants in these countries.

We then modelled the impact of preventive interventions on lowering caries-related direct costs. A combination of upstream and downstream interventions for prevention was envisioned that would facilitate a reduction of 30% in the annual caries progression rate. With these interventions, the greatest reduction in per-person costs was seen in the most deprived group in all countries except Indonesia. Using a levelling-up approach, where interventions applied are proportional to the need and the caries progression rate of the least deprived group is applied to all individuals, the per-person reduction in direct costs among the most deprived groups ranged from \$3,948 in Indonesia to \$17,728 in the UK. These data make a strong argument for instituting preventive management with a particular focus on narrowing the gap between the highest and lowest socioeconomic groups.

The way forward

The WHO Oral Health Strategy includes recommendations on aligning both upstream and downstream care towards the prevention and management of oral diseases. For both periodontitis and caries, there is an urgent need for better alignment between policy, public health, payments systems and clinical practice.

Expand and diversify the oral health workforce

Dentists alone cannot rise to the challenge of instituting preventive care and narrowing inequities. Expansion and recognition of allied dental care professionals, including dental hygienists/therapists and oral health educators, are key to expanding preventive efforts. Engaging pharmacists and nurses at their point-of-contact with patients can also be a very valuable tool. A collaborative approach between medical and dental professionals to cooperatively target preventive efforts for oral health and other common NCDs must be encouraged through education and training.^{28,29} Designing health systems that provide holistic oral health care from multiple health professionals is pivotal to successfully scaling preventive care.

Incentivise preventive care

Payment models for dentists should move away from perverse incentives that promote a restorative/repair approach. Dentistry has advanced, payment systems need to follow suit. There should be alignment of payment with preventive care that addresses common risk factors for all NCDs. The Alliance for a Cavity-Free Future (ACFF) has developed a new remuneration system for dentists that rewards dental practices for improving access to better quality care, offering better outcomes like lower risk of caries and collecting clinical data. This system is being piloted in France, and, if successful, it will be a model for replication and scaling.³⁰ Another example is the National Health Service (NHS) dental reform introduced in England, which encourages personalised follow-ups for patients based on their oral health status. This approach could free up oral health professionals to better focus their time on patients with greater needs, offering counselling and preventive care.³¹ Such funding and payment mechanisms that “level up” access to, and outcomes from, prevention and treatment with a greater focus on the most deprived should be prioritised.



Engage the population by raising awareness

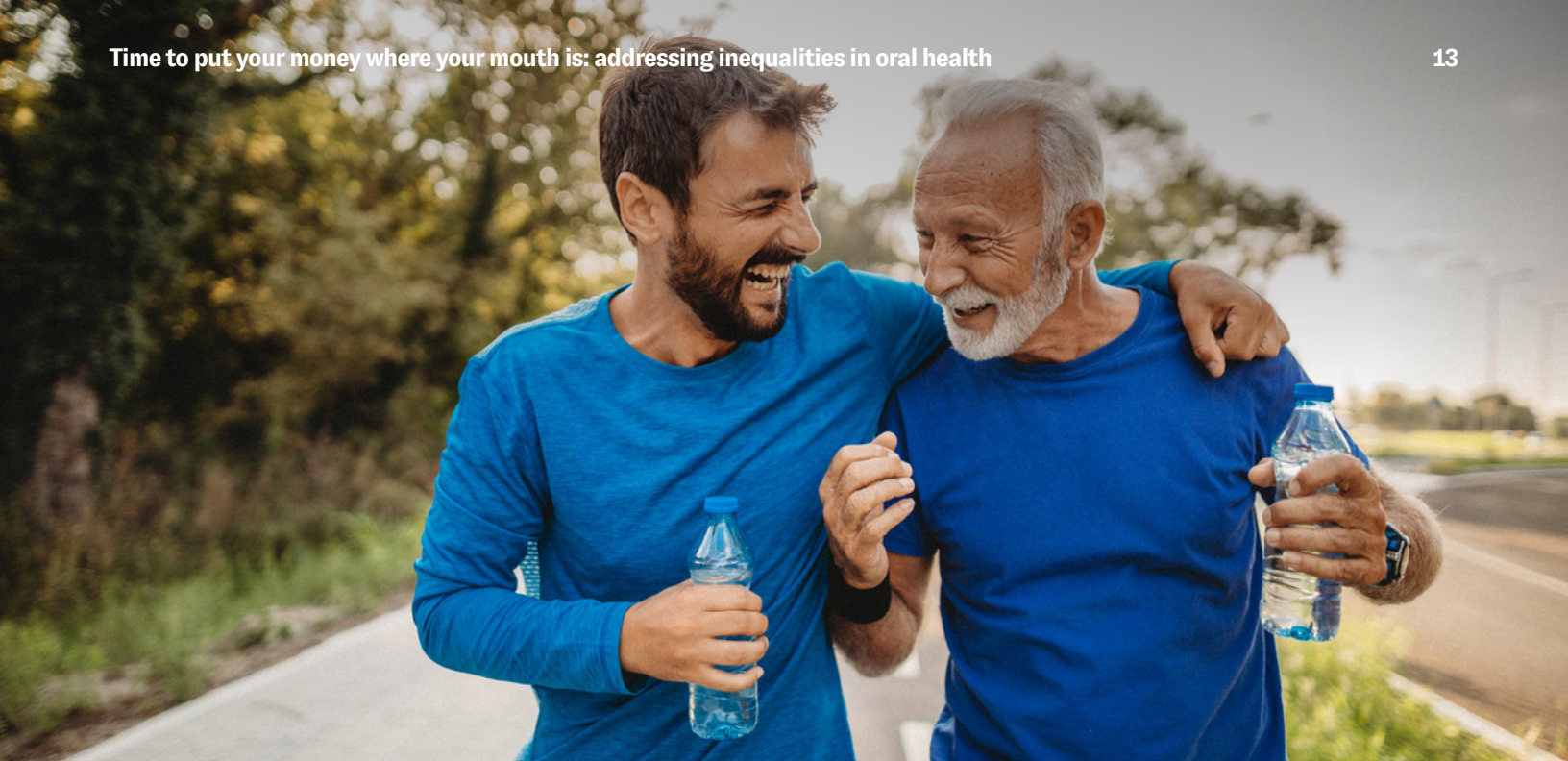
For prevention efforts to succeed, it is important to empower the population with oral health education and practical support for behaviour change. Good oral health habits and caries experience in childhood track through adolescence into adulthood. Therefore, educating parents about the benefits of preventive oral care is essential to promote oral health and lower the prevalence of oral diseases. Our experts suggested that this education should begin as early as the antenatal period. The WHO recommends a minimum of four antenatal care visits and three postnatal care visits for every mother.^{32,33} Including official recommendations to integrate oral health counselling into one or more of the antenatal and postnatal care visits will facilitate the implementation of such a strategy. The United States provides a free set of resources called “Protect Tiny Teeth” to facilitate conversations between healthcare providers and mothers on the importance of oral health in children with tips to protect the oral health of their infants.³⁴ Incorporating such materials into the WHO recommendations may have far-reaching impact. Special attention must be paid to educating healthcare professionals in primary

health centres in both rural and urban areas, in order to improve the reach among the most deprived. Efforts should gradually be expanded to include fathers in the conversation. The first 1,000 days of a child’s life, from conception to the second year, is a crucial “window of opportunity” to provide such education that has a lasting impact on health behaviours.³⁵

School health programmes are very effective in reaching children; preventive oral health education should be expanded in these programmes, with national governments providing guidance on how they should be implemented. As for adults, mass media and social media campaigns have shown benefits in improving preventive oral health behaviours. Efforts should be targeted to reach the most deprived.³⁶ For maximum impact, oral health messages and advice should be simple, easy to follow and contain visual aids in an effort to overcome any potential literacy challenges.

Build public-private partnerships to promote population-level prevention

There is a need for a shift in how we consider the commercial determinants of health. The prevailing view on the impact of corporations is largely negative and fails to recognise the value of several companies that provide oral health products or healthy foods. Engaging in partnerships with such corporations could be beneficial to oral health promotion efforts. A transdisciplinary approach that includes health care professionals and their representative bodies, public health professionals, industry, economists and policymakers should underpin these efforts. The WHO has developed a programme called the “Economic and Commercial Determinants of Health” that aims to support countries to work in partnership with the private sector to establish common health goals and address conflict of interest.³⁷ Countries could leverage these insights to make headway in this space.



Address shared risk factors with other NCDs to improve overall health

Viewing health holistically, there should be a “common risk factor approach” to address oral health simultaneously and efficiently with other NCDs within a wider socio-environmental milieu. Given the close linkage between oral health, other NCDs and their risk factors, experts are advocating for oral diseases and simple/refined sugars to be included in a revised 6 x 6 framework of NCDs at the national policy level. Such efforts will be key to gather political, economic and scientific attention to the problem.⁷ At the implementation level, there is more work being done to induce family physicians and oral health professionals to collaborate and co-manage oral diseases along with systemic NCDs.^{28,38}

Improve epidemiological methods to measure early caries and periodontal disease

The Decayed, Missing, and Filled Teeth (DMFT) index is the most common method used for assessing and measuring dental caries in epidemiology studies of oral health. However, the index was developed more than 80 years ago, and while it is considered easy to apply, it excludes pre-cavitation stages from the measurement of the caries lesion, which is key for a more modern and preventive approach to oral health.³⁹ Instead, epidemiological measures for oral health that identify early lesions suitable for preventive management should be employed to assess the burden of caries. Ideally, these measures should be easy to collect by front-line professionals and validated against quality-of-life metrics. A number of effective measures have been developed that are capable of capturing a wider spectrum of caries disease presentations, allowing for less invasive and more preventive care. These include widely recognised caries assessment tools.^{40,41,42,43,44}



Collect data and enhance transparency

Our previous research on periodontal diseases identified the paucity of relevant data as a major limitation to the research. We found that epidemiological data on periodontal diseases is inconsistent and even missing in some European countries.

Similar data challenges were found in trying to quantify the health burden and direct costs of caries for this report, with several gaps in data regarding caries prevalence, progression and cost of care. These data gaps required us to make assumptions regarding inputs, posing some limitations to our modelling exercise. The benefits of preventive measures can be accurately quantified only with better longitudinal data collection. Efforts to improve preventive oral health care should be accompanied by robust data collection to prove its impact. Population-level, cross-sectional data regarding the proportion of people paying for dental care either out-of-pocket, through insurance premiums or mixed schemes should be made available. Cost data for publicly funded dental treatment by country (and at the sub-national or community-

level) should be published to better understand health system implications. Longitudinal studies should be conducted to study the health and economic effects of introducing a simple set of preventive oral health measures on people with no caries or early caries. Studying the benefits across socioeconomic groups will be important in enhancing the impact on the most deprived populations through targeted preventive strategies. These data on cost savings will be pivotal to galvanise support among policymakers.

Despite periodontitis and caries affecting close to half of the world's population, there is a striking lack of political focus in this area. The 2019 Global Burden of Disease (GBD) study's data on their rising burden were pivotal in pushing these diseases into the limelight, leading to a landmark Resolution on oral health being passed by the WHO in 2021.²⁰ This Resolution recommends pivoting to a preventive approach and integrating oral care with other NCDs in the pursuit of UHC.⁶ While there is still a long way to go, with strong political will and concerted efforts in education and preventive interventions, the elimination of periodontitis and caries may, in fact, be a fathomable dream.

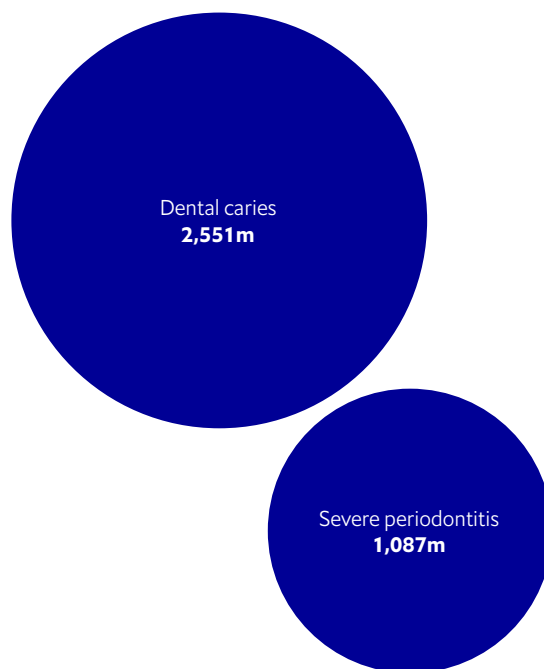
Introduction

Oral health has been relegated to the shadows for years. Such neglect is surprising given that almost half of the world's population — close to 3.5bn people — suffer from oral diseases. Globally, the number of patients with oral

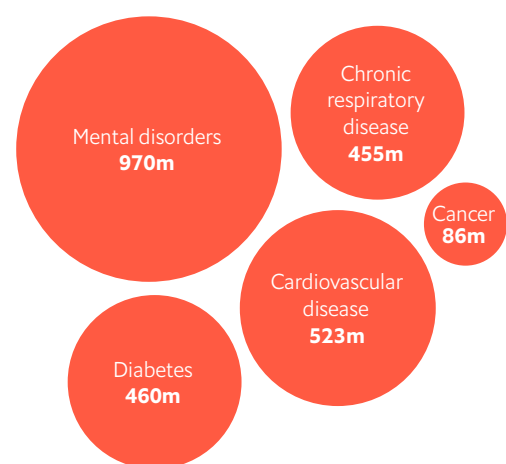
diseases outstrips the total number of patients with the five most prevalent non-communicable diseases (NCDs), such as mental illness, cardiovascular disease, diabetes mellitus, chronic respiratory disease and cancer, by almost 1bn.¹

Figure 1: Comparison of estimated global case numbers for selected NCDs

Prevalence of the 2 most common oral diseases
Combined: 3,639m



Prevalence of 5 of the most common NCDs
Combined: 2,494m



Source: Global Burden of Disease, 2019⁴⁵



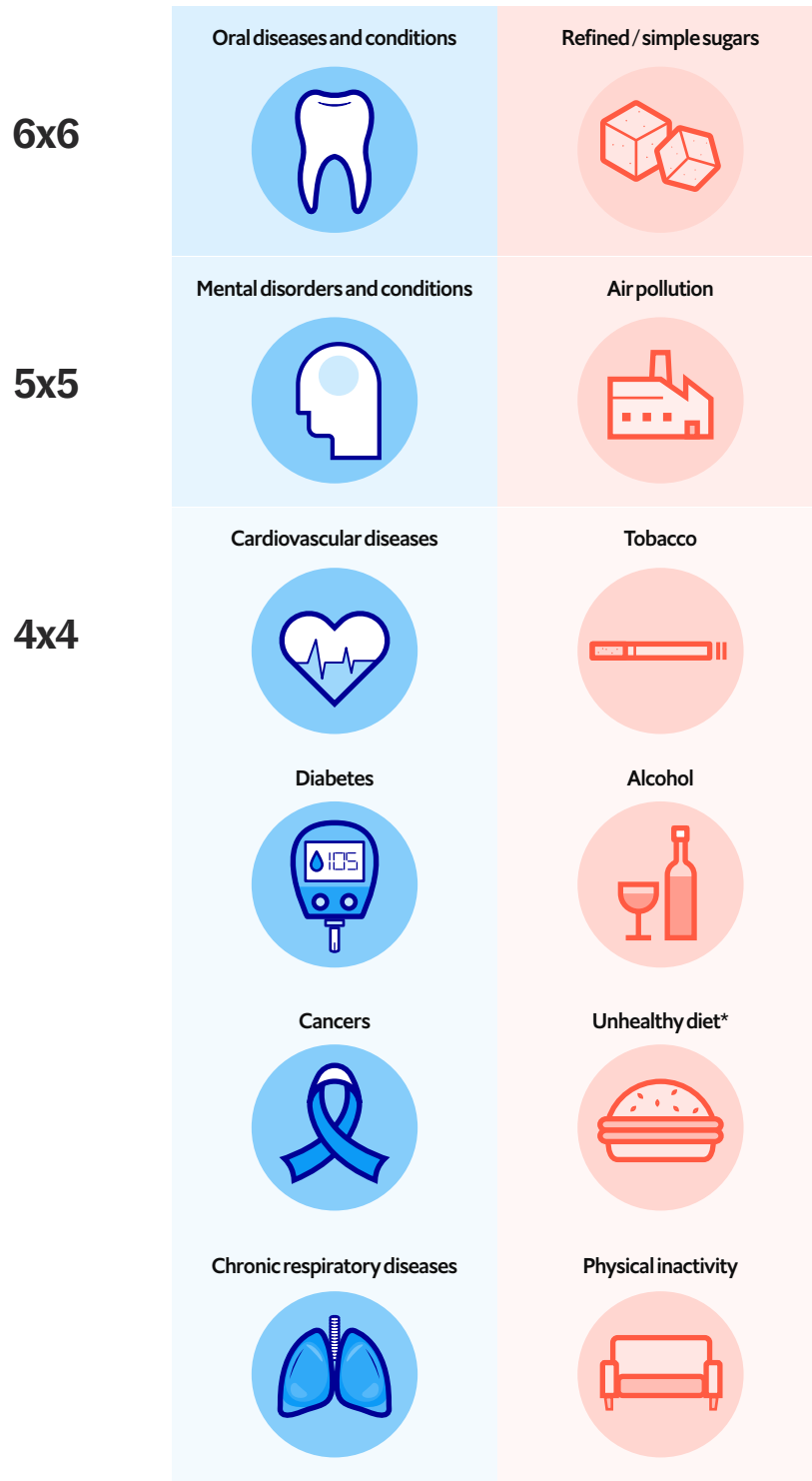
The most prevalent and consequential oral diseases globally are dental caries (tooth decay), periodontal disease (gum disease), and cancers of the lips and oral cavity. Dental caries is the most common oral disease, affecting about 2bn people worldwide. Severe periodontitis ranks second with over 1bn cases globally. This high prevalence is striking given that dental caries is preventable by reducing the dietary intake of sugar, improving oral hygiene and using fluoride. Improved oral hygiene also reduces the risk of periodontal disease.^{46,47} About 7% of people over the age of 20 are estimated to have tooth loss, which is usually a consequence of severe caries and gum disease.

Even though oral diseases and conditions share common risk factors and interlinkages with other NCDs, they have been siloed from the remaining healthcare system in models of provision and funding. Risk factors for dental caries and periodontal disease, such as smoking, alcohol consumption and a diet rich in sugars, also increase the risk of other leading NCDs like diabetes, heart disease, cancer and stroke. Oral diseases and NCDs share similar social and commercial determinants of health, thereby being more likely to cluster together in certain groups of people.⁴⁸ Oral diseases also predispose patients to NCDs and vice versa.⁴⁹

For example, a longer duration of poorly controlled diabetes is associated with an increased prevalence and severity of periodontal disease. Conversely, chronic periodontal inflammation may worsen diabetes control.⁵⁰ Periodontitis is also associated with other systemic illnesses such as cardiovascular disease, rheumatoid arthritis, obstructive sleep apnoea, chronic obstructive airway disease and covid-19-related complications.^{51,52} The association of dental caries with iron deficiency anaemia and mental illnesses has also been demonstrated.⁵¹

The current mainstream framing for NCDs adopts a 5 x 5 framework where the five most prevalent (non-oral health) NCDs and their risk factors are prioritised. The notable absence of oral diseases here is an important factor that impacts political, scientific and economic attention to this problem. Given the close relationship between oral health, other NCDs and their risk factors, experts are advocating for oral diseases and simple/refined sugars to be included in a revised 6 x 6 framework at the policy level (Figure 2).⁷ On the ground, there is a push for family physicians and oral health practitioners to improve collaboration to facilitate early diagnosis and co-management of oral diseases and other NCDs such as diabetes.^{53,54}

Figure 2: Selected NCDs and risk factors



Source: Adapted based on Benzian H, Daar A, Naidoo S. Redefining the non-communicable disease framework to a 6x6 approach: incorporating oral diseases and sugar. Lancet Public Health. 2023;S2468-2667(23) 00205-0.

The impact of oral diseases and conditions are disproportionately higher among socioeconomically disadvantaged people. Lower levels of education, occupation and income are associated with a higher prevalence and severity of oral diseases and conditions across all ages.² “There is a very clear social gradient in oral health, [with] every lower socioeconomic group having a worse prevalence of oral diseases,” shares Georgios Tsakos, Professor of Dental Public Health at University College London (UCL). Despite the greater severity, deprived populations have poorer access to oral care.² It could also be argued that the pandemic has further amplified problems with oral health and access to oral care. Wearing a mask for prolonged periods has been associated with “mask mouth” due to increased mouth breathing and decreased salivary flow rates. Early manifestations of mask mouth include dry mouth and bad breath, which over time can progress to caries and gum disease.⁵⁵ Closure of schools during the pandemic resulted in disruptions of school-based oral health programmes.¹⁹ Oral care for adults has also been compromised due to pausing elective dental services as part of the pandemic response, creating backlogs of care and a move away from prevention to intervention.

The 2021 Adult Oral Health Survey in England revealed that 35% of adults required dental treatments during the pandemic between March 2020 and March 2021, but almost half of those in need (16%) did not seek treatment. Of those who did not seek treatment, 13% cited the inability to pay. However, of those in the lowest income quintile, 34% in need of care didn't seek help because they could not afford to pay for it, suggesting that service gaps during the pandemic have further exacerbated inequities.⁵⁶

The sidelining and siloing of oral diseases and conditions have been pinned in part on the lack of adequate and reliable data regarding this burden. The 2019 Global Burden of Disease (GBD) study brought oral diseases into the limelight, describing untreated caries as the most common health condition among adults and children under 14 years of age. The GBD data showed a 46% increase in the total number of individuals with caries of permanent teeth between 1990 and 2019.²⁰ The number of prevalent cases of severe periodontitis increased by 99% in the same timeframe.⁵⁷ With this catapulting of oral diseases to the forefront, the World Health Organization (WHO) adopted a landmark Resolution on oral health in 2021. The Resolution urges a range of actions, including the integration of oral health into national health policy, pivoting to a preventive approach for oral health and integrating oral health into the NCDs and Universal Health Care (UHC) agendas.⁶ But this is a tall order, considering the financial challenges that healthcare systems already face. Innovative solutions are therefore key to realising this vision.

In our previous report titled, “Time to take gum disease seriously”, our modelling work demonstrated the positive return on investment (ROI) of using home-based preventive care and facilitating earlier diagnosis and management of periodontitis across six European countries.²⁸ To expand on this work, our current report will examine the cost of inaction in dental caries, and the potential direct cost reductions from greater prevention and control measures. Using the quantitative data from economic analyses and qualitative data from expert insights, we suggest a framework for policy development towards universal oral healthcare by emphasising the integration of preventive management across different NCDs.

The scale of the problem

Oral diseases are the most common health condition worldwide and pose a significant economic burden. Global estimates in 2015 suggested that the total worldwide costs of dental diseases amounted to about \$544bn. Around 66% of these expenses were due to treatment expenditures and the rest were due to productivity losses. The highest per-capita dental expenditures were seen in high-income regions, possibly due to the greater likelihood of patients seeking care and using more expensive treatment technologies.⁵⁸ However, middle-income countries are not far behind. According to Melissa Adiatman, Lecturer at the University of Indonesia's Department of Dental Public Health and Preventive Dentistry, "Treatment for oral problems was among the top ten causes of highest healthcare expenditure in 2020 and 2021 in Indonesia."

A study evaluating the overall costs of periodontal disease across the United States and Europe in 2018 estimated the burden at \$154.1bn and €158.6bn, respectively.⁵¹ Dental caries, the most common oral health challenge, is likely to place a huge economic burden on healthcare systems on its own. However, estimates of this are limited, especially in the adult population. Marko Vujcic, Chief Economist & Vice President of the Health Policy Institute at the American Dental Association, discussed his previous experience with economic estimates of dental caries with

the Alliance for a Cavity-Free Future (ACFF) Make Cavities History Taskforce, which estimated that the global economic burden of caries was at least \$245bn.⁵⁹ Caries accounts for 5-10% of healthcare budgets in industrialised nations. Caries is also a leading cause of hospitalisation among children in some high-income countries.⁶⁰ Estimates of the economic burden of periodontal disease and caries from low- and middle-income countries are sparse. Filling these data gaps should therefore be a priority.

Paula Vassallo, President of the European Association of Dental Public Health, looks at the bigger picture when it comes to the economic burden and potential opportunity to improve population health and save finite resources for the health system. "Oral health is like the canary in the coal mine. If an individual has oral health problems, what is going to be the cost of all the additional factors? Not only the economic burden in terms of absenteeism and presenteeism from work, but also other NCDs." Given the shared risk factors with multiple NCDs, she asks, "If somebody has dental caries, what is their likelihood of being obese or having diabetes? So, this needs to be considered when thinking about the wider economic burden of oral health. With that, oral health can be viewed as the gateway to understanding what your future will look like in terms of oral diseases and NCDs."

Socioeconomic, cultural and commercial determinants of oral health

Socioeconomic determinants of health play an important role in the development of periodontal disease and caries. The 2019 GBD data showed that regions with low Social Development Index (SDI) had a higher prevalence of gum disease than those with a high SDI.⁶¹

A similar relationship between low socioeconomic status and increased risk of caries has also been observed, as decay and deprivation often go hand-in-hand. The 2019 GBD data attributed 64.6m cases of dental caries to sociodemographic inequality. Caries prevalence in both deciduous and permanent teeth was found to be lower in countries with higher SDI. This was attributed to improved awareness of Early Childhood Caries (ECC) among the public, resulting in behavioural modification and greater resources dedicated towards improved dental public health programmes and preventive management. The disproportionate impact of lower socioeconomic status on children was notable; children aged 5-9 years old showed the largest proportion of caries of permanent teeth attributable to inequity (27%).²⁰

The second National pathfinder study in Italy, which included more than 7,000 12-year-olds, showed a correlation between the prevalence and severity of caries and macroeconomic and microeconomic indicators. Increased prevalence of childhood caries was noted in regions of Italy with lower socioeconomic status, higher income inequality and higher unemployment rates. At the individual-level, the prevalence of caries was higher among children whose parents had a lower education level, lower working status and high smoking habits.⁶² Lower educational status has also been correlated with an increased risk of periodontitis.⁶³





Various cultural factors also impact oral health. Cultural beliefs regarding the causes and best treatments for oral conditions impact patients' care-seeking behaviour. A recent systematic review reported that religiosity and spirituality are protective factors against oral diseases, though the review also highlighted that the quality of the evidence is low.⁶⁴ Tooth or oral tissue mutilation and tooth modification, including dyeing of teeth, is practised in some cultures, which may compromise oral health.⁶⁵ Commercial determinants of health, which are private sector activities that affect people's health, can play a key role in either improving or propagating oral diseases. "This is a very touchy subject but extremely important. The impact of the commercial determinants of oral health can be both good and bad," says Professor Domenick T Zero, Director of the

Oral Health Research Institute and Professor in Indiana University School of Dentistry's Department of Cariology, Operative Dentistry and Dental Public Health. On the one hand, large companies manufacture products such as fluoride toothpaste that are integral to reducing the burden of oral diseases. The flip side is that powerful corporations are also involved in promoting products that are detrimental to oral health, including tobacco, alcohol, and sugar-rich foods and beverages. Many of their marketing activities increasingly target emerging economies, lower middle-income countries and vulnerable populations. These countries face the greatest pressure from transnational companies due to food insecurity, decreased access to nutritious food choices, and reliance on corporations for occupation and income.⁶⁶


Impact of oral health challenges on well-being widens the gap further

The WHO defines oral health as “The state of the mouth, teeth and orofacial structures that enables individuals to perform essential functions like eating, breathing, and speaking. This also encompasses psychosocial dimensions such as self-confidence, well-being, and the ability to socialise and work without pain, discomfort, and embarrassment.”⁶² As the definition highlights, poor oral health not only affects physical well-being but also significantly impacts the quality of life (QoL). The impact of poor oral health on wellness results in impaired productivity and decreased work opportunities, further widening the gap between rich and poor, and increasing inequities.

Oral health-related quality of life (OHRQoL) refers to the specific impact of oral health challenges on individuals’ physical, psychological, and social well-being. The impact of periodontal disease on OHRQoL has been demonstrated by different studies. A systematic review including 34 studies showed that both gingivitis and periodontitis negatively impact adults’ QoL. Severe periodontitis impacts patients by causing pain, functional limitation, physical and psychological disability.⁶⁷ It is also associated with difficulties in social life, negatively impacting both personal and professional relationships, due to bad breath and changes in the appearance of teeth affected by the disease.⁶⁸

Symptoms of caries include pain, discolouration of teeth, bad breath and altered taste. Caries symptoms in children impair social behaviour and result in learning difficulties, impacting the QoL of children and their families. A systematic review, including 24 observational studies with 21,555 preschool children, showed that ECC resulted in two times greater odds, and severe ECC in five times greater odds, of poorer OHRQoL among affected children. Functional and psychological domains of QoL were the most affected. Severe ECC also impacted the QoL of families due to work disruptions, financial challenges and feelings of guilt.⁶⁹





“An additional economic burden that often isn’t considered is that poor oral health impacts people’s ability to economically support themselves, with one-third of the low-income population in the United States reporting that oral health issues limit their job interview ability.”

Dr Marko Vujicic, Chief Economist & Vice President, Health Policy Institute, American Dental Association, United States

Compromised OHRQoL due to toothaches and impaired social behaviours, such as smiling and talking, can contribute to low social capital, as evidenced by a cohort study in Brazil. In this study, 1,134 12-year-old adolescents were followed for six years and it was shown that untreated dental caries directly correlated with low social capital, likely due to impaired social behaviours. Social capital was measured at the individual-level using the attributes of social participation, level of empowerment and social networks.⁷⁰ Low social capital among adolescents affects physical, emotional and intellectual well-being; an association of low social capital with increased youth unemployment has also been demonstrated.^{71,72}

According to Sonia Chaves, Director of the Faculty of Dentistry at the Federal University of Bahia (UFBA), periodontitis leads to lower self-esteem, difficulties with emotional intelligence, and even unemployment due to tooth loss. Dr Vujicic agrees on the employment challenges, adding that “An additional economic burden that often isn’t considered is that poor oral health impacts people’s ability to economically support themselves, with one-third of the low-income population in the United States reporting that oral health issues limit their job interview ability.”

Access to dental care: a challenge, especially for the deprived

According to WHO estimates, there are around 4m oral health providers globally, of whom around 2.5m are dentists. About 80% of these dentists work in high-income or upper-middle income countries, while only 1.4% are estimated to work in low-income countries. The highest dentist-population ratio is seen in Europe (5.7 per 10,000), while parts of Africa report a meagre ratio of 0.33 per 10,000.²⁶ Currently, only ~23% of the global population is estimated to have access to oral health services. The WHO aims to increase oral health care coverage to 80% by 2030.²⁷

Within countries, lower-income groups and rural populations have greater barriers to accessing dental care. Corrado Paganelli, Chair of the International Federation of Dental Educators and Associations (IFDEA) and Dean of the University of Brescia's Dental School, describes

the situation in Italy where the public dental service "covers all children below 14 years of age" or "fragile populations" but most others must pay out-of-pocket. "The refugee population in Italy is increasing, but their oral care is not covered at the institutional-level, but voluntary associations cover most of their needs," Prof Paganelli adds. Yet, he estimates that about 60% of people in Italy do not attend regular dental appointments, typically due to financial barriers. Diah Ayu Maharani, Professor at the University of Indonesia's Department of Preventive and Public Health Dentistry, describes the rural-urban divide in access to oral healthcare in Indonesia. She notes that most dentists in Indonesia work in urban areas and usually do not go to peripheral islands to offer their services. Mobile dental care is offered to rural populations but it still does not reach the more remote populations.



Dr Chaves explains how socioeconomic status impacts the care options when more deprived populations do actually access care, saying that “The lower-income population engages in an economic analysis known as ‘economic economy’, in the sense of Pierre Bourdieu, when in need of dental treatment. If they need a root canal, they will consider the high cost

and maybe think I won’t be able to cope. So, the most common practice is a more invasive extraction. In fact, in some regions of Brazil, especially in the countryside or areas with a low human development index (HDI), you have a ratio of maybe two to one where dentists extract twice as much as they restore.”

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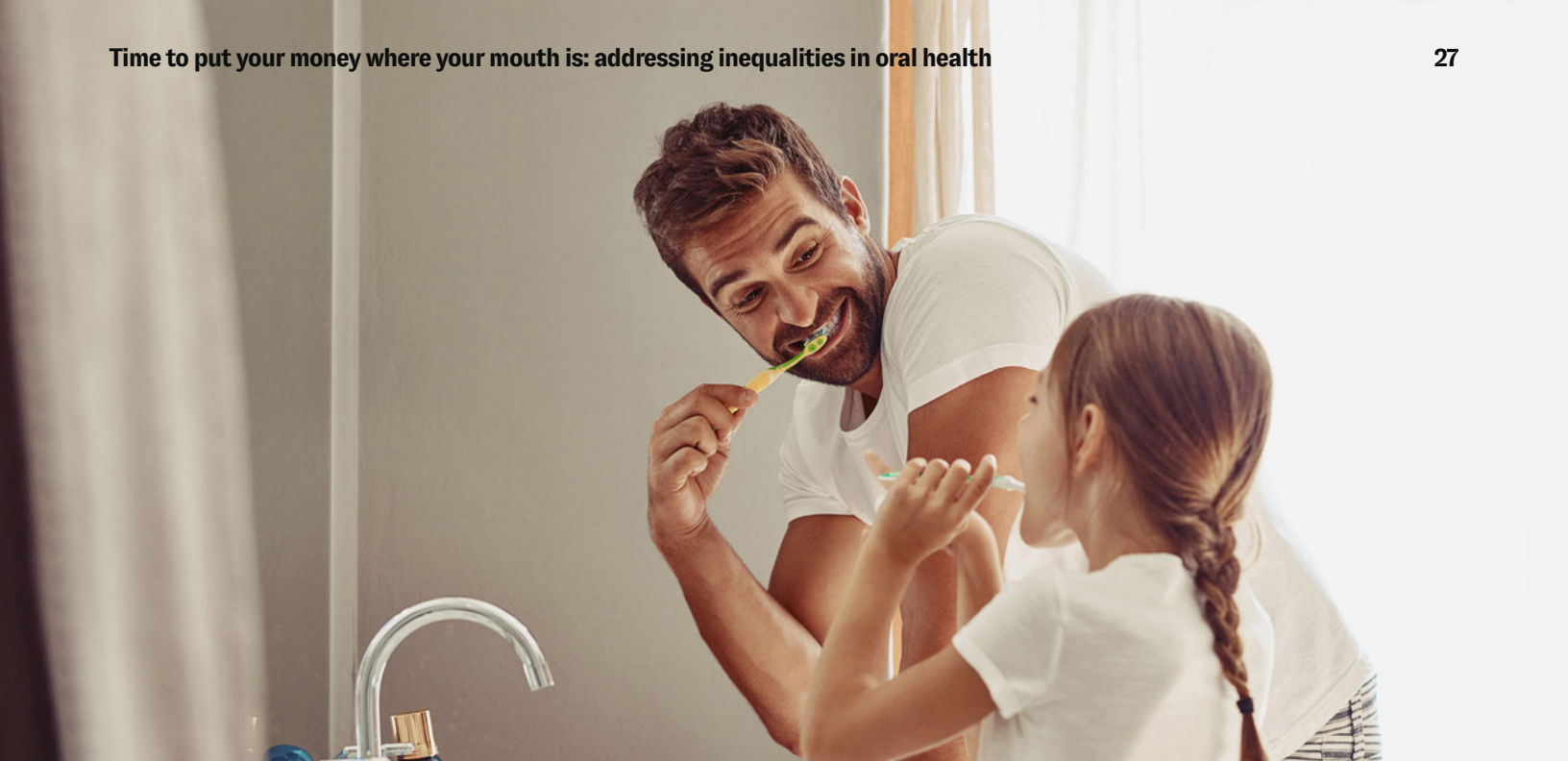
Professor Sonia Chaves, Director, Faculty of Dentistry, Federal University of Bahia (UFBA), Brazil

Preventive care in oral health: a pressing need

A paradigm shift in our understanding has moved gum disease and dental caries from the infectious disease realm into the NCDs spectrum.^{3,73,74} For several decades, certain bacteria in the oral cavity were thought to be the cause of gum disease and caries — efforts were directed towards their eradication. However, our understanding of the human microbiome has evolved — we now know that these and other bacteria are present in the oral cavity in a healthy state.³ The microbes in the oral cavity in healthy individuals interact with the tooth's surface to form a biofilm called dental plaque — a normal phenomenon. A decrease in saliva or excessive dietary intake of free sugars can disrupt the beneficial balance of microbes seen in the plaque. The acidic environment near the plaque created by a diet with high levels of refined/simple sugar facilitates the growth of acid-loving or acid-tolerant bacteria, which results in caries.⁴ In the early stages, caries can be reversed by dietary changes and the use of fluoride. However, once cavities are formed in the teeth, the condition is no longer reversible and may eventually culminate in the need for tooth extraction. A sugary diet also increases

oxidative stress and inflammation, predisposing one to periodontal disease. Gingivitis is reversible, but if left unchecked, it can cause progressive destruction of the surrounding bone, a condition termed periodontitis. Eventually, periodontitis results in tooth loss.⁷⁵ In addition to diet and smoking/tobacco use, obesity and diabetes also increase the risk of both caries and periodontitis. While genetic factors confer an increased risk for these oral diseases, modifiable risk factors play a more pivotal role.⁷⁶ Therefore, preventive care through individual- (downstream) and population-level (upstream) measures are key to lowering the disease burden.

Prevention of periodontitis and caries at the individual-level requires maintaining good oral hygiene, reducing dietary intake of sugars and cessation of tobacco use.^{46,47} Cleaning between teeth is also critical to lowering periodontitis risk.¹³ Application of fluoride to the teeth — through toothpaste, varnish or sealants — facilitates remineralisation, seals pits and fissures between the teeth, and lowers caries susceptibility.^{46,47}



The WHO recommends various simple, safe, and cost-effective measures for promoting oral health based on these principles.¹⁰ Tooth brushing twice a day with toothpaste containing 1000-1500ppm of fluoride is recommended for self-care. This practice inhibits the growth of bacteria, facilitates remineralisation of teeth, and lowers the risk of caries and periodontal disease. "If the population brushes their teeth with fluoridated toothpaste 2-3 times a day, there will be a gradual decline of caries experience in all age strata across the population, and in 20-30 years the prevalence of caries will decrease dramatically," notes Senior Professor Thomas Kocher, Department of Restorative Dentistry, Periodontology, Endodontology, and Preventive and Pediatric Dentistry, University Medicine Greifswald, Greifswald, Germany. He adds that in Germany, the burden of dental caries has reduced substantially with this intervention. Although fluoridated toothpaste is widely available globally, it remains inaccessible and unaffordable for low-income communities. In addition to regular tooth brushing, it is recommended to clean between the teeth at least once daily using an approved interdental cleaning aid. This could be dental floss, interdental brushes, or irrigators. Performing this cleaning prior to tooth brushing helps maintain gum health and prevents the accumulation of food in areas that are difficult to clean with a toothbrush alone, which could lead to cavities. Regularly applying fluoride varnish

to teeth every three to six months is another effective method to prevent caries and arrest early decay. Varnish application is simple and can be performed in a primary healthcare centre or a community setting such as a school. Sealants seal the convoluted grooves on the biting surfaces of back teeth that are particularly prone to caries attack. This forms a physical barrier that blocks the entry of microorganisms and food particles into these fissures. Such sealants can be used as a primary prevention strategy before caries develop or as a secondary prevention measure to stop the disease from advancing. The main types of sealants are resin-based and glass-ionomer cements.^{11,77} Glass ionomer cement, which slowly releases fluoride, is recommended by the WHO as a sealant, given its ease of application and efficacy.¹² To improve access to fluoride toothpaste, varnish, and glass ionomer cement, all three agents have been included in the WHO model list of essential medicines for adults and children in 2021. In 2023, low- and high-viscosity resin-based composite as well as silver diamine fluoride were further included in the WHO model list. The WHO action plan aims that for 50% of countries to include dental preparations in their National Essential Medicines List by 2030.^{78,79,80} Efforts at the population-level that can reduce periodontitis and caries include legislation against smoking and taxation on sugar and tobacco.^{81,82} Increasing tobacco taxes is the most cost-effective way of reducing tobacco use.⁸³

According to the WHO's recently published "Global report on the use of sugar-sweetened beverage taxes, 2023", more than half of the world's population (57%) lives in countries that implement national-level taxes on sugar-sweetened beverages (SSB). Examining the most-sold brand of sugar-sweetened carbonated beverages globally, the WHO found that excise taxes represent just 6.6% of the price of soda. While no best practices for effective SSB excise tax levels currently exist, larger tax and price changes are needed to significantly impact the consumption of SSB.⁸⁴ Implementing extra taxation for SSB has shown benefits in reducing sugar consumption and potentially lowering caries risk, especially in people of lower socioeconomic status.^{8,82,85} It should be noted that almost half (46%) of countries that tax SSB also tax healthier substitutes such as unsweetened bottled water.⁸⁴

Community water fluoridation is a population-level measure that effectively lowers caries risk. A systematic review of 20 prospective controlled studies showed that water fluoridation decreases the number of children with caries of either deciduous or permanent teeth.⁸⁶ A cross-sectional study performed in the United States demonstrated that water fluoridation can narrow the income inequality gap of caries in children with deciduous teeth. However, children in low-income groups were less likely to live in predominantly fluoridated counties.⁹ A scoping review, which included 24 articles, showed that water fluoridation is a cost-effective strategy for averting caries and reducing the need for dental treatments.⁸⁷ Despite these benefits, attention must be given to ensuring appropriate levels of water fluoridation. Excessive fluoride intake can result in tooth staining called dental fluorosis. In more extreme cases, there can be damage to internal organs like the bones and kidneys.^{88,89}

A combination of downstream and upstream interventions is necessary to prevent oral diseases.⁹⁰ Such preventive efforts can be cost-effective and even cost-saving. Economist Impact's previous modelling work has shown that eliminating gingivitis through simple, home-based oral care techniques would be hugely cost-saving over a 10-year period as compared to the status quo. This modelling exercise included six European countries, France, Germany, Italy, the Netherlands, Spain and the United Kingdom (UK). The primary objective was to estimate the ROI for gingivitis prevention and management as well as periodontitis management. A willingness-to-pay approach determined the monetary value of improved care – each healthy life-year gained was valued at 2.5 times the GDP per capita.



The baseline scenario modelled the business-as-usual approach based on the current management of gum disease. The baseline costs ranged from €18.7bn in the Netherlands to €96.8bn in Italy over a 10-year period. If gingivitis management was reduced to 10% of the baseline scenario, a negative ROI was seen in all countries. A similar finding of negative ROI for all countries was seen when periodontitis was never managed. In a scenario where 90% of mild/moderate periodontitis was diagnosed and treated, there was an increase in costs in all countries, ranging from €60bn in Spain to 290bn in Italy over 10 years. However, despite the higher costs, the ROI was positive in all countries and it resulted in the second highest Health Life Years (HLY) gained for all countries except in the Netherlands, where it resulted in maximum HLYs gained. The “best buy” approach was the scenario of eliminating gingivitis through

improved oral hygiene and home care. It cost less than the business-as-usual scenario, and gave the maximum positive ROI and the maximum HLYs gained, except in the Netherlands, where it produced the second-highest gain in HLYs. The study demonstrated that considerable costs can be saved over a 10-year period through this preventive approach, ranging from €7.8bn in cost-savings in the Netherlands to €36bn in Italy.²⁸

As part of our current project, we developed the “caries prevention and care cost calculator” that aims to: 1) determine the longitudinal direct costs of management of dental caries between the ages of 12 and 65 years across different socioeconomic groups and 2) the potential reduction in direct costs from non-targeted and targeted oral health-promoting interventions. The assessment was conducted for six countries: Brazil, France, Germany, Indonesia, Italy, and the UK.



Caries prevention and care cost calculator

Methods

We developed a conceptual framework to illustrate the progression of caries from a healthy tooth to a carious white spot (initial), lesion (loss of mineral from the tooth surface), followed by established tooth decay, then a compromised tooth pulp (blood and nerve tissue in the central part of the tooth), and eventually an unsalvageable carious tooth (Figure 3). The framework also includes interventions for primary prevention at various stages to prevent the development or limit the progression of caries. Preventive interventions on healthy teeth or those with carious white spots include maintaining good oral hygiene by brushing with fluoridated toothpaste, applying fluoride, and sealing the pits and fissures on the crowns (biting surfaces) of teeth. Once there is established tooth decay, the carious process cannot be reversed and management of the condition moves into a “restorative reparative cycle”, and may include several stages of treatment. Initially, it may receive multiple fillings. If the decay progresses to compromise the dental pulp, the tooth will require a root canal treatment with or without a crown. If left untreated, the decay may progress to a point where the tooth is unsalvageable, necessitating a tooth extraction followed by replacement with an implant (if available).

Informed by this conceptual framework, we developed a more simplified approach to the dental caries clinical pathway to enable a feasible assessment and estimation of the economic burden of dental caries, based on the available data (Figure 4).^{91,92}

The estimates of the current population in the 10-14 year age group were obtained from the World Population Prospects, and the WHO probability of death data was used to project the population estimates forward to the 60-64 year age group.^{93,94} The population in each age group was then divided into deprivation quintiles (least deprived, second least deprived, middle deprived, second most deprived and most deprived). Based on this relative ranking system, we assigned 20% of the population in each-age cohort into each deprivation quintile. For this, an assumption was made that the average income distribution across the total population is the same across all age groups.

Figure 3: Conceptual framework of dental caries pathway of care

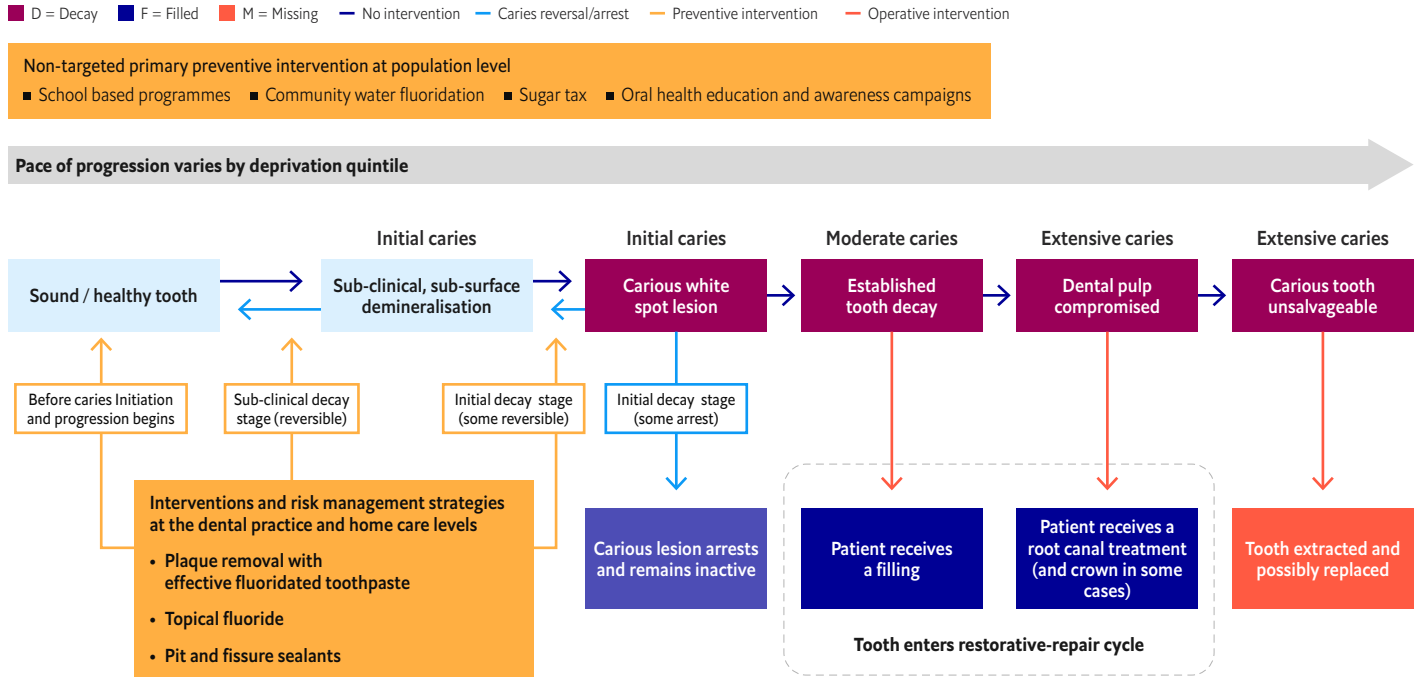
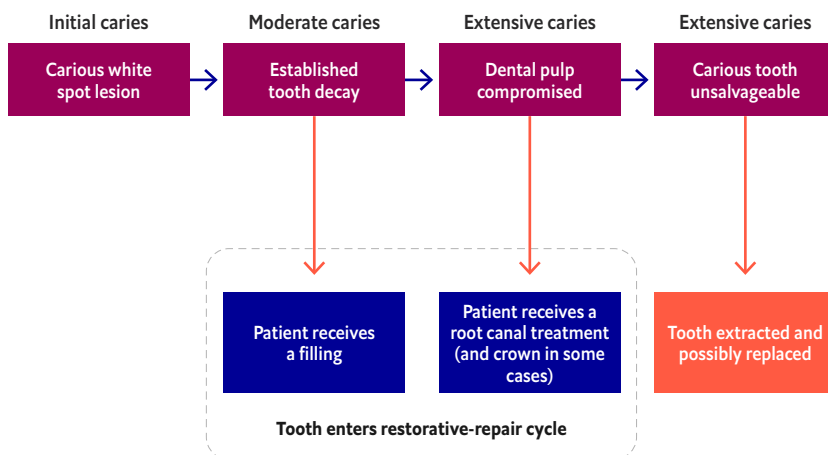


Figure 4: Framework for analysis





DMFT (Decayed, Missing, and Filled Teeth) at the caries into dentine threshold is the most commonly used scoring system to quantify current and past caries experience.^{95,96} Country-specific sources were used to determine the baseline DMFT scores at 12 years.^{97,98,99,100,101,102} Of note, UK data was extrapolated from a national survey including England, Wales and Northern Ireland. The difference in DMFT scores between the least and most deprived quintiles was estimated at 0.4, with the most deprived quintile having the highest DMFT score or highest caries burden.¹⁰³ The DMFT scores obtained from the national oral health surveys were assumed to be the score of the middle deprived group, and conversion factors based on the Gini coefficient of the countries were used to determine the DMFT experience of the other quintiles. Data from a systematic review were used to assign the annual rate of caries progression, which was adjusted to different deprivation quintiles based on the likelihood of them receiving preventive care and management for caries.¹⁰⁴ The costs of various caries management measures in the private sector were used to estimate the direct costs of caries in the population and by deprivation quintiles. We then estimated how these costs would decrease with the institution of preventive care.

This work aims to advance discussion of the caries element of the global oral health challenge through the development of a novel pragmatic framework, which recognises:

- the potential for variation in the progression rates of caries lesions through the different stages of lesion severity over the life course
- the current inequalities in caries initiation, progression, prevention and treatment
- the costly impact of the traditional restorative/reparative cycle of repeated and increasingly expensive operative/surgical caries care
- the different levels to which some population groups can access the full spectrum of treatment options

This allows for the calculation, from existing data at the country-level, of the economic burden of caries and the potential for lowering inequalities through a levelling-up approach to dental caries.

The cost of inaction in caries

Disproportionately high health and economic burden of caries in the most deprived

At the population-level, the overall direct costs of caries in people aged 12-65 years varied from \$10,284bn in Italy to \$36,231bn in Brazil, which is partly explained by differences in population sizes; the largest per-person costs were estimated in the UK (\$22,910) and they were lowest in Indonesia (\$7,414). The direct costs of caries were highest in the most deprived group across all countries except Indonesia and Germany, where it was highest in the least deprived, followed closely by the most deprived (Tables 1 and 2).

The most deprived groups had the highest DMFT scores at baseline (age 12) in all countries, which partly explains the higher direct costs in this group in the UK, Italy, Brazil and France. A greater ECC experience is seen in the most deprived, which is often untreated, resulting in higher DMFT scores following through to age 12 and beyond. The National Dental Epidemiology Programme for England performed a survey of 5-year-olds in 2018, reporting that more than one-third (34%) of children in the most deprived group had caries experience compared to 14% of the least deprived.¹⁰⁵ In Southern Brazil, a study of the Pelotas birth cohorts of 1993, 2004 and 2015 showed a decreasing prevalence of untreated ECC over time in the 4-6 years age-group. The greatest risk of untreated caries was seen in the

lowest income quintile compared to the highest quintile, with the disparity widening over time. The relative risk of untreated caries in the lowest income quintile compared to the highest was 1.4 in 1993, 1.8 in 2004 and 4.2 in 2015.¹⁰⁶ These data highlight the need for earlier intervention in the most deprived population to improve the overall disease trajectory and burden.

Our analysis does not include hospitalisation costs as part of direct costs because caries is most often managed in dental clinics. However, it should be noted that a recent systematic review reported that the most deprived populations have higher emergency visits to hospitals for non-traumatic dental issues and are more likely to be admitted for caries management.¹⁰⁷ A study in Western Australia examining oral-health-related hospital admissions reported that patients in the most deprived quintile were 2.7 times more likely to be admitted for dental caries than the least deprived group.¹⁰⁸ Data from the NHS in 2022 showed that hospitalisation for tooth extraction was 3.5 times higher among children and young adults in the most deprived communities as compared to the least deprived.¹⁰⁹ Management of caries, in addition to dental procedures, also requires medical treatment such as painkillers, mouthwashes and antibiotics. Therefore, if hospitalisations and medications were included, the actual direct costs are likely to be even higher, especially in the most deprived.

Our model estimates costs for caries management in the private sector and extrapolates this to all individuals receiving caries care in the population. This is likely to be an overestimation for countries like the UK which has a large public-led dentistry service, as well as Germany and France where the government subsidises the private costs.

Regardless, these estimates are an approximation of the societal costs to both individuals and the government. Limitations are inherent in any economic modelling exercise, and this study is no exception. The limitations of this analysis, which are largely due to data availability constraints, are described in the Appendix.

Table 1: Costs of caries in the population aged 12–65 years (US\$)

Economic burden

Lowest  Highest

	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

Table 2: Costs of caries (per-person) in the population aged 12–65 years by deprivation quintile (US\$)

Economic burden

Lowest  Highest

	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

Preventive interventions have greatest cost reductions for the most deprived

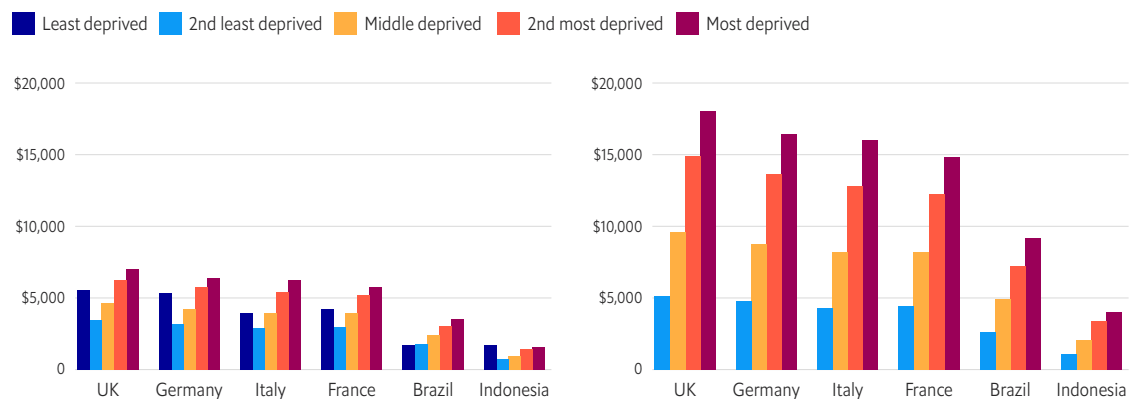
We sought to model the impact of preventive interventions on the prevalence of caries experience and costs. Research has highlighted the positive impact of a range of oral health promotion and oral disease preventive interventions, such as water fluoridation, taxes on unhealthy food and beverages, twice-a-day brushing with fluoridated toothpaste, and health behaviour education (diet and oral health practices), to prevent caries.^{82,86,110,111}

Considering that tooth decay is almost entirely preventable, we estimated the reduction in direct dental costs using a conservative estimate, reducing the annual caries progression rate by 30% in our cohort. The estimates are intervention-agnostic and

are therefore not specific to any individual- or community-level intervention. With this slowed progression, the greatest decrease in per-person costs for caries management was seen in the most deprived group across all countries except Indonesia (Figure 5, Panel A).

Following this, a “levelling-up” or “proportionate universalism” approach was conceptualised, with prevention and management interventions targeted at the scale and intensity proportional to the degree of need across deprivation quintiles. With this method, an annual caries progression rate of +0.07, which originally pertained to the least deprived group, was then applied across all quintiles. The per-person reduction in care costs in the most deprived group approached a high of almost \$17,728 in the UK and the savings were over three times higher in the most deprived group as compared to the second least deprived group in all countries (Figure 5, Panel B).

Figure 5: Decrease in per-person costs (US\$) after:
(Panel A) uniform application of non-targeted interventions lowering the progression rate by 30%
(Panel B) a levelling-up approach to reduce caries progression



Towards levelling the playing field

Preventive oral care is the cornerstone of establishing universal dental care. “Oral health strategies need to prioritise preventive oral health and minimally invasive care. This is the only evidence-based approach to improve access to oral care and level the playing field, while reducing the costs to the health care system in the long term. Such an approach can eventually facilitate the provision of an essential dental care package to the general population,” opines Wagner Marcenes, Chair of the Affordable Health Initiative and Professor-in-Residence at King’s College London.

Improve estimates of early caries where preventive measures can be applied

To enable the expansion of preventive oral health programmes, we must have better estimates of disease burden, costs of treatment and cost savings of preventive measures. “We have rich but inconsistently collected dental caries data for children but data for adults is not collected on a systematic basis in most countries,” observes Nigel Carter, Chief Executive of the Oral Health Foundation. Our study has looked to address the gaps in data regarding caries for adults through modelling estimates. While important insights have been gained regarding the disproportionate health

and economic burden on the most deprived populations and the magnitude of potential benefit to them with preventive interventions, several assumptions were required due to the paucity of data. National health surveys of caries prevalence in 12-year-olds were dated, data regarding variability in caries prevalence based on deprivation status had to be extrapolated from Germany and Wales, and information regarding types of treatments received for caries based on deprivation status was lacking. Information on costs of treatment in the private sector were fragmented and variable. There is room for improved data collection in all these domains.

“Oral health strategies need to prioritise preventive oral health and minimally invasive care. This is the only evidence-based approach to improve access to oral care and level the playing field, while reducing the costs to the health care system in the long term.”

Professor Wagner Marcenes, Chair, Affordable Health Initiative; Professor-in-Residence, King’s College London, United Kingdom



“We haven’t reduced the disease burden, we’re just placing more fillings. Success, right? Because that’s our measure of success. We’re treating, and this serves dentistry very well, but I don’t think it serves patients as well as it could.”

Professor Domenick T Zero, Director, Oral Health Research Institute; Professor, Department of Cariology, Operative Dentistry and Dental Public Health, Indiana University School of Dentistry, United States

But critical to the implementation and success of preventive programmes is the determination of early carious lesions. Our modelling estimates rely on the DMFT score which is easy to perform and has high reproducibility. However, DMFT has several limitations including accounting only for cavitated lesions and not early caries. In order to advance oral health, Marco Mazevet, Consultant at Candesic, highlights that “for more than 20 years, researchers have been advocating that DMFT should not be used. But there’s been a remarkable resistance to change.”

Prof Zero opines that the use of “DMFT just reinforces our way of thinking. Basically, we’re interested in the disease burden, but really, what we focus on [using DMFT assessments] and consider a huge success is if we can move someone from the decay component to the filled component. In America, the only thing that we’ve achieved is that we’re placing more fillings. We haven’t reduced the disease burden, we’re just placing more fillings. Success, right? Because that’s our measure of success. We’re treating, and this serves dentistry very well, but I don’t think it serves patients as well as it could.”

The experts convened and the academic community are in agreement – epidemiological methods to assess the burden of caries should measure early caries, suitable for preventive management. Ideally, these measures should be easy to collect by front-line professionals and validated against quality-of-life metrics. A number of effective measures have been developed which are capable of capturing a wider spectrum of caries disease presentations, allowing for less invasive and more preventive care. These include widely recognised caries assessment tools.⁴⁰⁻⁴⁴ Prof Zero shares “where we can detect the early stages of the disease and use that as our outcome measure, we’re really shifting the focus from disease management and managing the disease by intervening to prevent caries progression, and that should be our measure of success.”

Move from a restorative to a preventive model to establish universal oral care

Remuneration for dentists is currently centred around restorative care; procedures such as “drilling and filling” for cavities are reimbursed, while preventive care is usually not. “I do not think we have enough money out there to manage dental caries by treating the consequences of the disease, especially when the rising costs of medical care and climate change impacts are considered. I think it is a fool’s errand,” explains Prof Zero. There was consensus among the experts interviewed that the “restorative model” is an outdated surgical “repair” model, whereas preventive oral care embraces modern “wellness models” that are more medical in their approach.

Even in countries that are moving towards universal dental care coverage, there is a lack of funding for prevention. Dr Adiatman explains that since 2014, Indonesia has had universal oral health care. Basic reparation is covered by national health insurance, but other treatments need to be sought in private healthcare and are very expensive. Furthermore, preventive management is not covered. Similarly, France implements UHC with partial dental coverage. Dr Mazevet argues that “If we do not fund the right procedures, the health of the population is not likely to improve. We fund almost all curative treatments, but we do not fund preventive care. This concept needs to change to develop more sustainable oral health care.” There was a clear consensus among the experts interviewed that payment systems for healthcare professionals (including the oral health team) need to be better aligned with prevention and reducing disease risk through addressing common risk factors for NCDs.

Importantly, some efforts are being made to move away from the current perverse incentives towards developing payment systems that encourage preventive and non-surgical care.¹¹² The ACFF has developed a hybrid model for payment of dentists that includes fee-for-service, pay-for-performance, and capitation-based remuneration. This remuneration system rewards practices that improve access to care for marginalised communities, have better clinical outcomes such as patients with fewer caries lesions, offer better quality of care, and collect clinical data.^{113,114} The new payment system is being piloted since 2021 in an oral health prevention experiment called EXPRESO (L’expérimentation prévention en santé orale) in France. About 600 dentists have been recruited to cover around 15,000 people, with over €6m invested in the project.³⁰ Patients are divided into risk groups based on their oral health, and practices are offered €120 for caring for those in the green risk group, €200 for amber risk and €275 for red risk. An external auditor will eventually perform an economic evaluation of the system, and a bespoke online system will be used to collect clinical data, patient-reported outcomes, and practitioner feedback.¹¹²

“If we do not fund the right procedures, the health of the population is not likely to improve. We fund almost all curative treatments, but we do not fund preventive care. This concept needs to change to develop more sustainable oral health care.”

Dr Marco Mazevet, Consultant, Candesic, United Kingdom; Vice-Chair, Public Health Committee, FDI World Dental Federation, Switzerland

The NHS dental reform introduced in England in 2021 similarly incentivises health education and preventive management. The contract requires dentists to arrange personalised follow-ups for patients based on their oral health status rather than having routine 6-month check-ups for everyone. This has freed up capacity in dental clinics where patients with more complex dental problems can now receive more frequent care. Dental practices have described how the extra time is spent on counselling and educating patients to support behaviour change and self-management.³¹ Dr Chaves highlights the preventative care gap in Brazil, saying that “most professionals don’t educate in the chair”, suggesting that dentists don’t receive such training, and adding that “a dentist who spends five years at university leaves without knowing how to teach patients to brush their teeth. This is a serious issue.”

Address inequities in access to oral health care

Successful universal dental care must focus on enhancing services for deprived populations while bridging the public-private and the urban-rural divide. Dr Adiatman describes efforts to achieve this in Indonesia, saying that “With dentists in Indonesia preferring to work in urban areas and the private sector, the government now requires graduating dentists to work in public health facilities of their choice for a year.” Similarly, creating “rural tracks” for dental education and practice and incentivising dentists to practise in rural areas through support for educational loan repayments are some strategies currently being explored in the United States.¹¹⁵

Augmenting the dental workforce by enhancing the involvement of dental therapists and dental hygienists can also help fill the gaps. This will require policymakers to include these professionals in the formal oral care workforce. Dental hygienists are recognised as a separate and licensed profession in many countries, such as Japan, Sweden, The Netherlands, Canada and

the United States, where they are considered key members of an oral healthcare team.^{116,117} Kenneth Eaton, Visiting Professor, University of Portsmouth; Honorary Professor, University of Kent; Adviser to the European Chapter of the Alliance for a Cavity-Free Future, shares that the role and impact of dental hygienists varies significantly across countries, where their clinical role may include procedures such as scaling, prophylaxis, placement of fissure sealants, taking and developing dental radiographs, administering local anaesthetic injections, and sculpting materials to fill cavities. Professor Eaton says, “In the United States, there are as many dental hygienists as dentists. Likewise in Canada, there are nearly as many. The best ratio in Europe is in Sweden, where there is one hygienist per two dentists. In the UK, we’ve got roughly one hygienist per five dentists, so there’s a long way to go here.” He also highlights that despite their important and impactful role in many countries, hygienists don’t exist within the dental workforce in France.

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Community dental health coordinators are also being trained in the United States to meet the oral care needs of underserved urban, rural and Native American communities.¹¹⁸ Such efforts could be replicated across other countries. “Oral disease prevention does not necessarily have to come solely from an oral healthcare professional. We need to bring in our medical colleagues, pharmacists and allied healthcare professionals who see patients regularly and could potentially have input here,” recommends Avijit Banerjee, Professor of Cariology and Operative Dentistry at the Faculty of Dentistry in King’s College London. Harnessing digital technologies, including tele-health and mobile health apps, could further enhance the reach of preventive dental care. Efforts are needed, however, to improve the quality and reach of such mobile apps.¹¹⁹

“Oral disease prevention does not necessarily have to come solely from an oral healthcare professional. We need to bring in our medical colleagues, pharmacists and allied healthcare professionals who see patients regularly and could potentially have input here,”

Professor Avijit Banerjee, Professor of Cariology & Operative Dentistry, Faculty of Dentistry, Oral & Craniofacial Sciences, King's College London, United Kingdom

Raise awareness about prevention, curb misinformation

Dr Mazevet explains that funding alone will not solve the problem of poor and inequitable oral health. “Universal dental coverage has just been implemented in France and there are zero out-of-pocket charges for 95% of dental procedures for 96-97% of the country’s population. Despite this, there has been no significant change in the number of patients seeking care from oral healthcare professionals. There are aspects beyond funding, like education and awareness, that need to be addressed,” he emphasises.

Prevention education should be improved at all levels and among all age groups. “The private sector of dentists in Indonesia organises an oral health day programme every year where people are encouraged to ask questions regarding oral health. Before the pandemic, dentists also offered free care on that day,” notes Professor Maharani. Among young people, school-wide dental education programmes are commonplace in the countries we studied. Prof Paganelli shares that school-wide education campaigns in Italy are strongly oriented towards prevention. The programmes are coordinated at the regional level and sometimes they are also supported by companies producing oral hygiene products. The experts interviewed for this report agreed that there’s a need to be proactive – to go a step further from just school health programmes to training community midwives to educate pregnant women on the importance of oral health. As midwives are often the first point-of-contact for pregnant women, they have the potential to play an important role in improving the oral health of pregnant women and subsequently their children’s overall oral health development. Involving parents and caregivers in caries prevention programmes, especially while transitioning infants from milk to solid foods, can be particularly impactful.²⁰

Governments need to play a key role in complementing these efforts by the healthcare sector to raise awareness. The “Dental Check by One” campaign, launched in the UK in 2017, has been established as a national guidance, and parents are encouraged to start visiting the dentist as soon as the infant’s teeth erupt, or by their first birthday.¹²⁰ In the United States, only toothpastes containing fluoride and proven to be safe and effective in reducing dental caries and maintaining oral health are given the American Dental Association’s (ADA) seal of acceptance.¹²¹

In the era of social media, education must go hand-in-hand with curbing misinformation. “There is already a lot of information made available to the public on the importance of using fluoride toothpaste. But there are some groups affected by digital influencers claiming that fluoride can cause brain damage,” notes Mariana Minatel Braga, Associate Professor at the University of São Paulo’s (USP) Department of Orthodontics and Pediatric Dentistry. She notes that “There is an urgent need to curb misinformation regarding fluoride use.”

Implement population-level prevention measures to bridge inequalities

“We have to be very careful when talking about health education,” Prof Marcenés cautions. “We can educate mothers, we can educate fathers, we can educate children, we can educate everyone, but without resources they cannot afford the high cost of adopting a healthy lifestyle,” he observes. Therefore, government investment in population-level prevention measures is key to tackling oral health inequalities.

Address the commercial determinants of health

“Humans are opportunistic eaters and if we overlay the commercial forces that exploit this and our preference for sweet foods, we can understand why there is a worldwide health crisis. As a society, we must work together to have a go at this. A transdisciplinary approach is necessary to target added-sugar, which is the main risk factor affecting oral health and other NCDs,” emphasises Prof Zero. Implementing a sugar tax could help reduce dietary sugar intake, eventually reducing the risk of NCDs, including caries. Brazil introduced taxation on SSB as early as 2013. However, contrary to global trends, there has been a progressive decrease in the SSB tax in Brazil over the past decade.¹⁷ France was one of the first European countries to introduce a tax on sweetened beverages. In 2018, the law was amended to introduce progressive taxation based on increasing sugar content rather than a flat tax rate, and the public health importance of this measure was highlighted. A cross-sectional



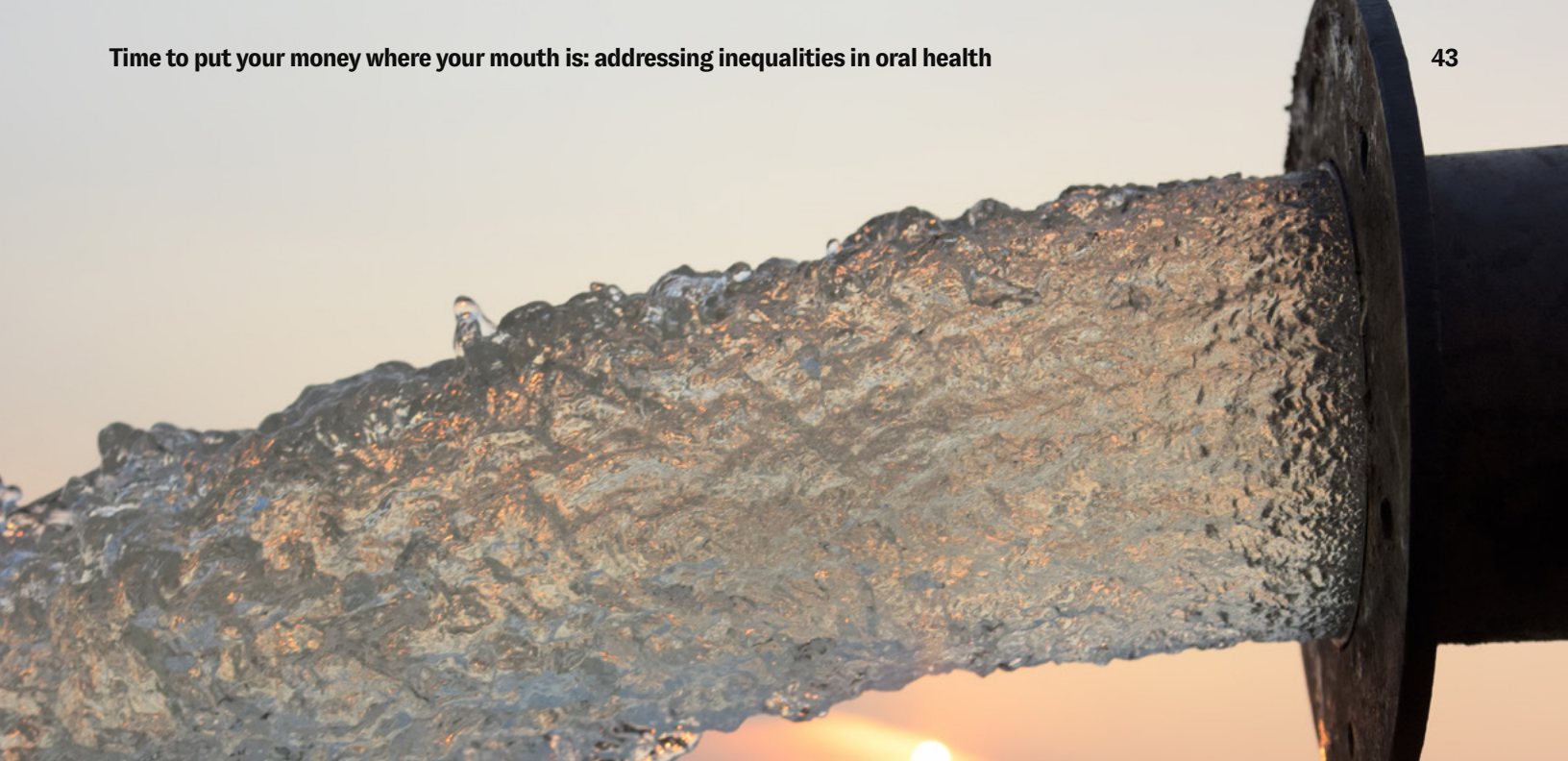
survey of around 28,000 adults showed that 65% favoured the taxation scheme, with the number rising to 76% if the tax gains were reinvested into the healthcare system. In 2018, the UK introduced the Soft Drinks Industrial Levy for sugar-containing soft drinks. It is estimated that over 45,000 tonnes of sugar have been removed from soft drinks after implementing the levy.¹⁶ Evaluation of the impact of the sugar tax in the UK was performed 22 months after its introduction, where changes in the incidence of hospitalisation for tooth extraction due to dental caries in children was studied between 2012 and 2020. A 12.1% relative reduction in hospital admissions was seen among children aged 0-18 years after the introduction of the sugar tax, and the difference was seen regardless of deprivation status. The highest reductions were noted for children between 0-4 years at 28.6%, followed by 5-9 years at 5.5%. No significant reductions were seen in older children (10-18 years).⁸⁵ However, strong political will is necessary to implement tax measures. Among the countries we studied, sugar taxes are yet to be implemented in Indonesia and Germany. Italy proposed a sugar tax in 2020, but the implementation has been repeatedly delayed due to strong opposition from corporate players.¹⁸

“We need to bring commercial stakeholders to the table. You’ve got the sugar industry, for example, making confectionery because people will buy them due to a sugar addiction. However, if they put their energy on making a profit on healthy foods, then public behaviour potentially changes overnight.”

Professor Avijit Banerjee, Professor of Cariology & Operative Dentistry, Faculty of Dentistry, Oral & Craniofacial Sciences, King’s College London

While the commercial determinants of health are primarily viewed negatively, Prof Banerjee highlights the key role industry stakeholders and commercial activity could have in driving better oral health. He explains, “We need to bring commercial stakeholders to the table. You’ve got the sugar industry, for example, making confectionery because people will buy them due to a sugar addiction. However, if they put their energy on making a profit on healthy foods, then public behaviour potentially changes overnight.” Furthermore, there are a multitude of commercial stakeholders in oral health promotion and disease prevention. Dr Chaves describes how the government in Brazil has engaged commercial stakeholders in an effort to improve oral health. “In 2000 and 2009, Brazil bought 90m tooth brushing kits. The government made a large purchase on the market of a kit with a toothbrush and paste, and distributed it to all the public oral health teams, and distributed it in vulnerable territories. The large purchase guaranteed a low toothbrush price.” Rather than a cost, Dr Chaves considers it an investment that aimed to address inequalities in oral health.

However, Dr Chaves informs us that “toothpaste is a problem in Brazil. Today, there are several small-scale industries manufacturing toothpaste that win public bids by claiming to have total fluoride in the formula. However, laboratory analyses do not confirm the presence of the caries-preventing Free Fluoride.” A recent study of toothpaste distributed by the primary healthcare public clinics in Manaus, Brazil, illustrates Dr Chaves’s point. The study examined 99 tubes of toothpaste from four commercial brands and found that only eight tubes from one brand contained a sufficient total fluoride concentration to control dental caries.²⁵ Therefore, Brazil is considering adopting a system where only toothpaste containing an adequate concentration of fluoride is labelled as “toothpaste”.



Promote fluoridation of the water supply

Fluoridation of the water supply can reduce caries. This practice already occurs in countries such as Brazil, but there are a diversity of challenges to its universal implementation. Sometimes, political will is lacking. Geographical barriers, as seen in Indonesia, can also play a role in preventing the fluoridation of the water supply. In addition, dietary habits need to be considered to ensure that overall fluoride intake is within the recommended range. Furthermore, many people drink water from local sources, such as wells, limiting the impact of fluoridation in the public water supply.

Introduce community-wide prevention programmes

The “Childsmile” programme in Scotland was launched to improve oral health among children and reduce disparities through toothbrushing, community-level support and varnish.¹²² The “Child Dental Health Act of Denmark” ensures free access to dental care for those under the age of 18 years. All children receive an invitation for preventive examination with a dentist starting between six and 12 months of age.¹²³ Similar programmes for children are seen across various countries in Europe.¹²⁴ The Brazilian National Oral Health Programme includes collective and individual prevention education for pregnant women, early contact with infants for preventive care by six months of age, and the incorporation of oral health education into vaccination campaigns. However, globally, community-based programmes for adults are generally lacking.

It is time to put the mouth back into the body – Integrate oral care and care for NCDs

Better collaboration and coordination between dental care professionals and other healthcare providers are critical to integrated care. To facilitate such collaboration, both medical and dental professionals must be trained from the undergraduate level to develop a holistic view of NCDs. The experts convened as part of this research highlighted the inadequacy of oral health education in medical students, with some students potentially receiving a “mouthless medical education”. The experts explained that medical students do not understand oral diseases and often perceive it as a completely different domain, separate from the rest of the body; it is clear that it is time to put the mouth back into the body.¹²⁵ A partnership of medical schools with dental schools or other private and community dentists will facilitate the incorporation of an oral health module into the medical curriculum. Learning objectives should include knowledge, clinical skill training and focus on interlinkages of oral health and other NCDs.¹²⁶

“Thousands of older adults in care homes and hospitals are dying unnecessarily because their mouths aren’t being cleaned.”

Professor Kenneth Eaton, Visiting Professor, University of Portsmouth; Honorary Professor, University of Kent; Adviser to the European Chapter of the Alliance for a Cavity-Free Future

Training dentists to provide basic screening and preventive primary care could also work to reduce disparities in NCDs management. The scope of practice for physicians and dentists in each other’s fields, however, must be clearly defined.¹²⁷ General practitioners (GPs) caring for patients with NCDs should be trained to identify common oral diseases and conditions, enabling them to make appropriate referrals when necessary. Providing workshops and training programmes for GPs can help build capacity to assist people with oral health problems, support oral health promotion and prevention activities, and establish more effective referral and communication channels between dental and medical practitioners.¹²⁸ Such training also benefits healthcare professionals working in tertiary care settings. Prof Eaton highlights the need for better integration of oral healthcare across settings, adding that “thousands of older adults in care homes and hospitals are dying unnecessarily because their mouths aren’t being cleaned.” Prof Eaton elaborates with an example of what he describes happens all too often “An 80-year-old lady is in hospital with a broken hip. Their hip operation goes well, but she’s also got arthritis and bad eyesight so she doesn’t clean her mouth. Neither do the nursing staff. The patient then inhales the bugs from her mouth, which should have been cleaned away and dies of pneumonia. Institutionally acquired pneumonia is a big killer, and it is so utterly unnecessary and avoidable.” These unnecessary deaths are what led the Department of Veterans Affairs in the United States to introduce the “Oral Health in Healthcare Settings to Prevent Pneumonia Toolkit”, after their pilot study revealed that a twice-a-day oral care initiative reduced non-ventilator-associated hospital-acquired pneumonia by 92% in its first year.¹²⁹

Conclusion

Oral diseases affect close to half of the world's population, and their burden has dramatically surpassed that of the most common NCDs. Despite now being recognised as NCDs, oral diseases are not included in the mainstream NCDs framework, and continue to be siloed from the management of other NCDs.⁷ There is a disproportionate burden of the most common oral diseases, periodontitis and caries, on the most deprived populations with the poorest access to care. Dental treatments are expensive and often provided through the private sector in many countries. Simply moving along the same path of "restorative and reparative" treatments by the dental workforce will not lower the disparities in care among socioeconomic groups. A huge opportunity for preventive care, which will greatly reduce the health and economic burden of oral diseases, remains untapped. A levelling-up strategy in preventive care can compound the gains achieved in the most deprived populations and narrow the gap in care access and outcomes. But, pivoting to a prevention approach in oral health needs multi-pronged, coordinated efforts.

For both tooth decay and gum disease, there is an urgent need for better alignment between policy, public health, payment systems and clinical practice. At the policy-level, oral health should be included in the mainstream framing of NCDs to direct political, scientific and economic attention to the area. Governments should develop public-private partnerships to pursue common oral health goals, particularly with corporations that are involved in oral health promotion efforts. A transdisciplinary approach should be used to engage with companies that drive oral health inequities. Payment models and funding for oral care should be set up in a way that incentivises preventive care, moving away from the dated restorative-reparative model. To better quantify the burden of oral diseases and the benefits of preventive care, epidemiological measures that identify early lesions suitable for preventive management should be employed in assessment. Robust collection of data on the health burden and costs are necessary to study the impact of preventive measures on cost savings. These data could be used to improve awareness across all stakeholders including the public, oral health professionals and policymakers.



**“There is no health
without oral health.”**

**Dr Paula Vassallo, President, European
Association of Dental Public Health, Malta**

Expansion of the oral health force by engaging nurses, pharmacists, dental hygienists/therapists and dental health coordinators with suitable training can improve coverage of preventive efforts. Collaborations between GPs and oral health professionals should be encouraged for the co-management of oral diseases with other NCDs.

Our study adds to a growing body of literature highlighting the high and unequal burden oral diseases place on the most socioeconomically deprived members of society. Despite almost half of the world’s population having an oral disease, oral health continues to suffer from a lack of political prioritisation. As Dr Vassallo highlighted, “There is no health without oral health.” Addressing inequalities in oral health will require decision-makers to recognise this fact, and a first step in that direction involves adopting the WHO’s recommendation for oral health to be integrated into the NCDs and UHC agendas. Although there is still a long way to go, with strong political will and concerted efforts in education and preventive interventions, the elimination of periodontitis and caries may, in fact, be a fathomable dream.

Appendix I: Methods

Data inputs

Population data:

The population size and age structure were determined for each country from the World Population Prospects (WPP), using the breakdown by five-year age groups.⁹³ The latest data for the 10-14 age cohort was used as a starting point, and was projected forward to when this age cohort enters the 60-64 group. Assumptions on death rates within each cohort were used to develop the projections. These assumptions were derived from the WHO data on the probability of dying at a specific age.⁹⁴

We used the WHO data on the probability of dying between 5-year age cohorts (prob_5yr) to the probability of dying at a specific age (prob_1yr) using the following formula:
$$\text{Prob}_{1\text{yr}} = 1 - \text{EXP}(\text{LN}(1 - \text{Prob}_{5\text{yr}})/5)$$

Each cohort was further disaggregated into five deprivation quintiles (least deprived, second least deprived, middle deprived, second most deprived and most deprived) based on the English Index of Multiple Deprivation 2019 (IMD 2019). Based on this relative ranking system, we assigned 20% of the population in each age cohort into each deprivation quintile.¹³⁰ For this, an assumption was made that the average income distribution across the total population is the same across all age groups.

Caries experience data:

The DMFT score refers to the number of Decayed, Missing and Filled permanent teeth and gives insight into both the current and past caries experience. It is the most commonly used population-based measure of caries experience globally.^{95,131} The DMFT score is calculated as the sum of all individuals' decayed, missing and filled teeth divided by the total population in that age group. DMFT scores for 12-year-olds were sourced from national oral health surveys in Brazil, France, Germany, Indonesia, Italy and the UK (Table 1).^{97,98,99,100,101,102} UK data were extrapolated from a national survey of England, Wales and Northern Ireland. These data were used as the baseline DMFT/caries experience. The average DMFT scores were multiplied by the population size in the age group to estimate the total caries experience in that age group.

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	0.1	1.9
Italy	0.71	0.36	0.02	1.09
UK	0.4	0.3	0.1	0.8

Population data:

The Dental Epidemiological Survey of 2016-2017 performed in Wales among 12-year-olds reported DMFT values using quintiles when detailing dental caries experience by socioeconomic status (SES). The survey reported a 0.4 difference in DMFT values between the least and most deprived groups in the survey.¹⁰³ Data on the DMFT scores/caries experience by deprivation group were not available for all the countries

in our study. Therefore, we extrapolated the Welsh data to the other study countries. In Germany, the Fifth German Oral Health Study (V Deutsche Mundgesundheitsstudie, V DMS) included DMFT data by SES, which was reported in tertiles (low social status, middle social status, high social status). The difference in DMFT values among 12-year-olds in the low versus high social status groups was 0.4, which aligns with the variation in the Welsh sample.¹³² We used quintiles to obtain narrower estimates.

We assumed the average DMFT data reported in each country's national oral health survey applied to the middle deprived quintile. We then used conversion factors estimated from Welsh data to adjust DMFT scores for all other quintiles. To estimate DMFT across deprivation quintiles for other countries, we adjusted the conversion factors based on the Gini coefficient of the respective country relative to the Gini coefficient of the UK to account for different degrees of inequality across countries (Table 2).¹³³

The calculation used was:

$$DMFT_{1i} = DMFT_{5i} * (DMFT_{5UK} / DMFT_{1UK}) * (GINI_i / GINI_{UK})$$

Where:

DMFT_{1i} is the DMFT score for the most deprived quintile in country i;

DMFT_{5i} 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

Table 2: Average DMFT in 12-year-olds by country and deprivation 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

Caries progression:

An annual increment in DMFT score of +0.18 was applied to the middle deprived cohort. The progression rates were adjusted across the deprivation groups with the annual progression rate in the least deprived group being +0.07. These data points were based on evidence from a large systematic review and meta-analysis that showed an unadjusted annual increment in DMFT rates of +0.18 and a decrease in DMFT progression rates from +0.18 to +0.07 per year following preventive and management interventions. We assume that the +0.07 estimate applies to the least deprived quintile, with the greatest access to interventions. Progression rates were then assumed to evolve across income brackets linearly.¹⁰⁴ Using these calculations, we arrived at the rate of annual progression of DMFT scores:

- 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 regardless of the baseline caries experience.

The overall annual progression rate in DMFT scores 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.¹³⁴ We assumed that the distribution of decayed, missing and filled teeth values reported in the Dunedin study were representative of the middle deprived quintile. These figures are described in Table 3. We then adjusted the distribution of decayed, missing and filled teeth in the other quintiles relative to the middle deprived quintile based on the likelihood of receiving a filling versus extraction. For instance, individuals in the most deprived group are more likely to receive an extraction rather than preventive management or restorative treatments like fillings, bridges and implants, even in countries like the UK with publicly-funded dental care. For example, in the 19-26 age group, the percentage of the least deprived group's increase in DMFT values for the missing component is 5.3%, while it is 10.7% and 19.3%, in the middle and most deprived groups, respectively.^{135,136}

Table 3: Assumptions used in the distribution of DMFT progression between age cohorts across deprivation quintiles

	12 years	13-18 years	19-26 years	27-32 years	33-38 years	39-65 years
Least deprived v middle deprived						
Decayed	Baseline	3.57%	51.7%	-35%	-43%	-24%
Filled	Baseline	96.4%	42.9%	110%	68%	33%
Missing	Baseline	0%	5.3%	25%	75%	43%
Second least deprived v middle deprived						
Decayed	Baseline	5.7%	56.7%	-37%	47.5%	26.3%
Filled	Baseline	94.2%	35.2%	107%	62.5%	27.7%
Missing	Baseline	0%	8.1%	30%	85%	46%
Middle deprived						
Decayed	Baseline	7.1%	60.7%	-40%	-50%	27.7%
Filled	Baseline	92.8%	28.5%	100%	50%	22.2%
Missing	Baseline	0%	10.7%	40%	100%	50%
Second most deprived v middle deprived						
Decayed	Baseline	10%	64.3%	-47.2%	-60%	30%
Filled	Baseline	90%	21.6%	92.2%	45%	10%
Missing	Baseline	0%	15%	55%	115%	60%
Most deprived v middle deprived						
Decayed	Baseline	14.3%	68%	-55%	-70%	31.8%
Filled	Baseline	85.7%	12.7%	75%	40%	3.2%
Missing	Baseline	0%	19.3%	80%	130%	65%

Direct costs of managing caries

The direct costs of managing caries in the private sector in our countries of interest were obtained through the triangulation of information gathered from experts in the countries and cost data sourced online, which are described in Table 4.

An increase in the F component of the DMFT index score by a value of 1 implied that the individual received a new filling. We assumed that a filling restoration is re-restored every 10 years, based on a conservative estimate of the median survival rate of composite fillings.^{137,138}

Among those who received fillings, we assumed that 9.3% underwent a root canal treatment. A systematic review, including 76 population-based studies with 32,162 people and 1,201,255 teeth, calculated the prevalence of root canal treatment as 9.3% of all teeth in Europe and this figure was used for our analysis.¹³⁹ It was assumed that a proportion of individuals who received root canal treatment also received a crown. The provision of root canal and crown interventions were weighted such that both were more common among the least deprived and less likely among the most deprived, due to the cost of the procedures.

Table 4: Costs associated with dental caries management per tooth (2023, in US\$, based on currency conversion rates on 12 June 2023)

	Filling	Root canal	Crown	Extraction	Implant	Alternative replacement*
UK	136	718	669	125	3,133	251
Brazil	69	213	500	43	540	43
Italy	158	349	460	58	2,052	164
France	105	662	755	93	1,980	158
Indonesia	25	117	151	26	1,010	81
Germany	129	645	1,000	38	3,051	244

*Besides dental implants, other options such as dental bridges or single-tooth removable partial dentures can 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 in comparison to a dental implant

Table 5: Provision of root canals and crowns across deprivation groups (%)

	Root canal	Crown
Least deprived	18	7.2
Second least deprived	12.5	3.75
Middle deprived	9	.18
Second most deprived	5.5	0
Most deprived	1.5	0

Table 6: Provision of replacements across deprivation groups (%)

	Receive single implant [^]	Receive cheaper alternative replacement	No replacement post-tooth extraction*
Least deprived	100	0	0
Second least deprived	80	20	0
Middle deprived	10	90	0
Second most deprived	0	70	30
Most deprived	0	40	60

An increase in the M component of DMFT by a value of 1 implied that the patient underwent a single tooth extraction. Once a tooth was extracted, we assumed that less deprived groups received single tooth implants, while the more deprived groups received a single tooth removable partial denture as the cheaper alternative treatment or no replacement. The provision of replacements across deprivation groups is detailed in Table 6.

The overall direct costs for caries in each age group were calculated as the product of the cost of treatment, the number of teeth requiring treatment, and the percentage of each deprivation group assumed to receive the relevant dental procedure. In this analysis, we applied the UK's National Institute for Health and Care Excellence (NICE) recommended discount rate of 3.5% for future costs.¹⁴⁰

Scenario analysis

We conducted two scenario analyses to estimate the decrease in per-capita costs from caries between 12-65 years of age:

Scenario 1 – Application of non-targeted interventions resulting in caries progression rates decelerating by 30% across all deprivation quintiles

Scenario 2 – A “levelling-up” or “proportionate universalism” approach, with prevention and management interventions targeted at the scale and intensity proportional to the degree of need across deprivation quintiles. The caries progression rate of the least deprived quintile was applied across all quintiles.

Limitations

There was a paucity of relevant data in the literature to inform all parameters included in this analysis, which led to various assumptions posing limitations to the estimates in our study.

- The baseline DMFT data were obtained from national oral health surveys across a range of years (2007-2018). With improvements in oral health in recent decades, this may have overestimated the burden of caries in countries where older data was utilised. However, a decline in children's oral health status was observed as a result of the covid-19 pandemic, which could potentially impact longer-term trends in oral health.¹⁹
- Data on dental caries by deprivation quintile were estimated based on data from a Welsh Oral Health survey. There might be a question about the transferability of this data to other countries' context. However, such an approach was necessary due to the lack of dental caries data reported by deprivation groups in some of the other countries. In an effort to account for this limitation, our analysis adjusts data collected in the UK context by differences in income disparities across countries, proxied by the Gini coefficient.
- Our analysis assumed a linear progression rate in total DMFT, which is a simplification of dental caries progression in reality. However, we based our progression rates on a systematic review of dental caries progression.
- The prevalence of root canal treatments was calculated based on the number of filled teeth rather than the total number of teeth, which would have resulted in an overestimation of costs due to root canal procedures. However, since root canal and crown treatments were preferentially weighted towards the least deprived, it is unlikely to have affected our findings of the highest costs of caries in the most deprived.
- Data regarding costs of management of dental caries are not widely published. Therefore, we relied on the reports of experts and online information from various care providers with regard to related costs. Given that these are costs in the private sector, there may be significant variability depending on the organisation offering treatment, even within the same country.
- Dental caries results in additional costs beyond the financial cost of management and treatment — such as productivity loss, school and work absences, quality-of-life impacts, among others — that have not been estimated or accounted for in our analysis, which likely underestimates the burden of dental caries and the benefit of interventions.

Appendix II: References

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