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Global burden and trends of oral disorders among adolescent and young adult (10–24 years old) from 1990 to 2021

Xingzhu Dai[1†], Manqiong Dai[2†], Yuee Liang[2], Xiaoyu Li[2] and Wanghong Zhao[2*]

Abstract

Objective To determine the patterns and trends in the global, regional, and national burden of oral disorders among adolescents and young adults (AYA) from 1990 to 2021.

Methods This is an epidemiological observational study that analyzed annual prevalence and disability-adjusted life years (DALYs) for oral disorders—including dental caries, periodontal disease, edentulism, and other oral conditions—among adolescents and young adults (ages 10–24) from 1990 to 2021. Data were sourced from the Global Burden of Disease Study (GBD) 2021. To assess temporal trends, the estimated annual percentage changes (EAPC) in age-standardized prevalence and DALY rates were calculated at global, regional, and national levels. The GBD 2021 also provides sociodemographic index (SDI) data across 204 countries and territories. Pearson correlation analyses were conducted to explore the relationships between age-standardized prevalence and DALY rates with the SDI and their respective EAPCs.

Results Globally, the prevalent cases of oral disorders increased by 17.1%, from 549.2 million in 1990 to 643.3 million in 2021, and DALYs rose by 22.2%, from 1.4 million in 1990 to 1.7 million in 2021. The overall age-standardized prevalence rate (EAPC = −0.07 [95% CI, −0.12 to −0.03]) decreased, while the age-standardized DALY rate (EAPC = 0.06 [0.02 to 0.11]) increased over the same period. While the burden of dental caries declined, the burden of periodontitis and edentulism significantly increased. A negative correlation was observed between age-standardized prevalence and DALY rates and SDI, while a positive correlation was found between the EAPC of age-standardized DALY rates and SDI.

Conclusions The prevalence and DALYs of oral disorders among AYA have risen over the past three decades, particularly due to the growing burden of periodontitis and edentulism. Notably, the most significant increases have been observed in Southern Latin America and South Asia. While the global decline in dental caries has led to a reduction in ASPR, the escalating burden of periodontal disease and edentulism remains a critical concern. These trends emphasize the urgent need for innovative prevention and intervention strategies to improve oral health for this demographic worldwide.

Keywords Global burden of disease, Oral disorders, Adolescent and young adult, Epidemiology, Public health surveillance

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Introduction

Oral health is a critical yet often under-recognized global health issue, with far-reaching implications for both individual and societal wellbeing [1]. During adolescence and young adulthood—key periods of development—poor oral health can severely compromise both physical and psychosocial wellbeing [2]. Changing global trends, such as dietary shifts, urbanization, and evolving lifestyle habits, are reshaping oral health patterns among adolescents and young adults (AYA). The increased consumption of sugary foods and beverages, particularly in urban areas and low- and middle-income countries, has led to rising rates of both dental caries and obesity [3]. Additionally, the growing use of tobacco products, including vaping and smoking, has emerged as a major risk factor for periodontal disease among young people [4].

Oral diseases, particularly dental caries, are widespread among AYAs, with untreated caries peaking between the ages of 15 and 19 and affecting millions worldwide [3]. Although periodontitis and edentulism are less common in this group, they remain significant oral health concerns [5]. Alarmingly, periodontitis is on the rise among younger adults, underscoring the urgent need for early preventive strategies [6]. The psychosocial impacts of oral disorders in AYAs, including dental caries and periodontitis, are especially severe [7]. These conditions can lead to significant emotional distress, negatively affecting self-esteem, social interactions, and overall life satisfaction. Poor oral health in AYAs may have long-lasting consequences, extending to their mental health and social well-being.

Furthermore, the broader implications of untreated oral disorders are concerning, as these conditions often worsen with age [8]. Untreated caries, periodontal disease, and early-stage edentulism in young individuals tend to progress into more severe forms, increasing the risk of chronic conditions such as tooth loss and systemic diseases. The link between oral health and overall health—including conditions like diabetes and obesity—is particularly concerning, as poor oral health in AYAs is associated with an increased risk of developing these conditions, which can have lifelong consequences [7, 9].

There are stark disparities in oral health across regions and countries, with oral diseases disproportionately affecting impoverished areas and further exacerbating health inequalities [3, 10]. In high-income countries, oral healthcare systems are often dominated by treatment-focused and increasingly technology-driven approaches. However, these systems tend to be trapped in an interventionist cycle that neither addresses the root causes of oral diseases nor adequately serves large segments of the population [11]. In many middle-income countries, the burden of oral diseases is considerable, yet oral healthcare systems remain underdeveloped and unaffordable for the majority [12]. The situation is most dire in low-income countries, where access to oral care is severely limited, leaving many without essential treatment or prevention [13]. Moreover, broader social, economic, and commercial changes in low- and middle-income countries may be increasing the risk of oral disease [14]. Globally, the number of AYA is at an all-time high and is expected to continue growing in the coming decades. This increase will be most pronounced in low-income countries, where significant reductions in under-5 and child mortality rates have occurred, while fertility rates remain relatively high [15]. As a result, comprehensive assessments of the burden of oral disorders among AYA across different regions are crucial for developing more targeted and effective prevention and control strategies.

AYA represent a crucial demographic group, where investing in their health not only brings immediate benefits but also supports their wellbeing into adulthood and positively influences the health of future generations [16]. Therefore, implementing effective interventions for oral disorders during this pivotal developmental stage can significantly improve global oral health outcomes and contribute to broader population wellbeing [17]. However, oral health among AYA has long been underexplored in global health research, particularly with regard to regional variations, temporal trends, and the broader socio-economic determinants influencing oral disease prevalence [18]. Previous studies have largely focused on cross-sectional assessments or regional data that fail to capture long-term trends. This gap is especially evident in the scarcity of data on the burden of oral diseases such as periodontitis and edentulism in younger populations [19, 20]. Although numerous studies have explored the relationship between socio-economic status and oral health, the impact of global socio-economic changes over time on the oral health burdens in AYA remains unclear [21, 22].

The Global Burden of Diseases Study (GBD) offers a thorough evaluation of the burden of oral disorders across 204 countries and territories, providing a valuable opportunity to analyze trends in oral health over recent decades [23]. In this study, we focus on three common oral conditions—caries of permanent teeth, periodontitis, and edentulism—and aim to estimate the patterns and trends in their prevalence and disability-adjusted life-years (DALYs) among AYA. The objective of this study is to determine the patterns and trends in the global, regional, and national burden of oral disorders—specifically dental caries, periodontitis, and edentulism—among adolescents and young adults (ages 10–24) from 1990 to 2021, in order to inform targeted prevention and intervention strategies.

Methods

Overview

This is an observational epidemiological study that utilizes data from the Global Burden of Disease Study (GBD) 2021. The GBD, spearheaded by the Institute for Health Metrics and Evaluation (IHME), is a comprehensive scientific initiative aimed at quantifying the impact of major diseases, risk factors, and intermediate clinical outcomes in a standardized manner [24]. This standardization enables comparisons over time, across populations, and among different health challenges. Initiated in 1991, the GBD has evolved over the past three decades, becoming increasingly detailed with each iteration by including more causes, risk factors, and locations, while enhancing the granularity of age group analyses. The GBD protocol was approved by the University of Washington Institutional Review Board, with informed consent waived due to the use of deidentified data. This study is reported in accordance with both the GBD Protocol [23].

Definitions

In this study, we examined the burden of oral disorders among AYA, including caries of permanent teeth, periodontal disease, edentulism, and other oral disorders. The latter category encompasses all oral conditions not classified as permanent or deciduous dental caries, periodontal disease, edentulism, or severe tooth loss. The estimates of the burden of oral disorders presented in this report are based on data from GBD 2021. A detailed mapping of the International Classification of Diseases, Ninth Revision (ICD-9), and Tenth Revision (ICD-10) codes to caries of permanent teeth, periodontitis, edentulism, and other oral disorders is provided in the supplementary materials (Supplementary Table S1). All estimates are reported for adolescents and young adults (AYA), defined as individuals aged 10–24 years [25]. This age range aligns with the Global Burden of Disease (GBD) Study, which categorizes AYA as a distinct group to better capture the specific health challenges that occur during this developmental phase [26]. The age group of 10–24 years has remained consistent across all GBD iterations since its inception, allowing for comparability of data over time. The division of the 10–24 age group into three subgroups—10–14, 15–19, and 20–24 years—has also been consistent [27]. These 5-year intervals enable more granular analysis of trends within the AYA demographic. Our estimates are presented by sex, in 5-year age groups (10–14, 15–19, and 20–24 years), globally and by region, covering the years 1990 to 2021. Regional estimates are classified geographically into 21 GBD world regions and 204 countries or territories. Additionally, the Socio-demographic Index (SDI) data for this study are available via the GBD 2021 Data Input Sources Tool and were used to categorize countries into five quintiles (low, low-middle, middle, high-middle, and high) for further analysis. The SDI serves as a summary measure representing the social and economic conditions that may affect health outcomes in a given location. Further details on SDI definition and calculation as well as the countries within each quintile are provided in the supplementary materials (Supplementary Table S2). All rates are expressed per 100,000 people per year, with age-standardized rates using the GBD world population standard.

Data collection

The data sources are accessible via the GBD 2021 Data Input Sources Tool, available on the Institute for Health Metrics and Evaluation website (https://ghdx.healthdata.org/gbd-2021/sources). An overview of GBD data collection, modeling, analysis, and dissemination is provided in the supplementary materials. Detailed information on the disease model for oral disorders can be found in the GBD 2021 methods appendices (https://www.healthdata.org/gbd/methods-appendices-2021/oral-disorders). For this study, we extracted the prevalence and DALY numbers and rates for oral disorders in the 10–24 age group using the GBD Results Tool (https://vizhub.healthdata.org/gbd-results/).

Statistical analysis

We calculated age-standardized rates (ASRs) per 100,000 individuals for oral disorders among AYA aged 10 to 24 years, using the following formula:

$$\mathrm{ASR} = \frac{\sum_{i=1}^{N} a_i w_i}{\sum_{i=1}^{N} w_i} \times 100{,}000$$

In this formula, a_i represents the age-specific rate for the i^{th} age subgroup, and w_i denotes the population count for the same age subgroup i based on the GBD 2021 standard population [28]. N refers to the total number of age groups.

The natural logarithm of changes in ASR is assumed to follow a linear trend over time, represented by the equation $y = \alpha + \beta x + \varepsilon$, where $y = ln(ASR)$, x is the calendar year and ε is the error term. Estimated annual percentage changes (EAPCs) in ASRs were calculated to assess the average trends in the burden of oral disorders at the global, regional, and national level over a given period [29], using the formula $100 \times (\exp(\beta) - 1)$. The corresponding 95% confidence interval (CI) was derived from a linear regression model. At the global level, we analyzed the overall trends in oral disorders among adolescents and young adults (AYA) from 1990 to 2021. Regionally, countries and territories were categorized

into 21 world regions based on the GBD classification, allowing us to examine regional differences in the burden of oral disorders. Additionally, at the national level, we evaluated trends in oral health outcomes using data from 204 countries and territories. We classified an ASR as increasing or decreasing if both the EAPC and its 95% CI were entirely above or below zero, respectively. If the 95% CI included zero, the change in ASR was considered statistically insignificant.

Additionally, a Locally Weighted Scatterplot Smoothing (LOWESS) model was used to examine the correlation between the burden of oral disorders among AYA and the SDI across 21 regions and 204 countries and territories [30]. Pearson correlation analysis was conducted to calculate the ρ indices and p values, assessing the relationship between oral disorders burden and SDI.

Furthermore, the age-standardized prevalence rate (ASPR) of oral disorders among AYA from 2022 to 2040 was projected using the Bayesian age-period-cohort (BAPC) model with nested Laplace approximations [31]. The BAPC model estimates hypothetical probability distributions based on three key factors—age, period, and cohort—by combining prior knowledge with sample data to derive posterior distributions [31]. Global age-standardized population data were sourced from the World Standards database, developed by the WHO (https://seer.cancer.gov/stdpopulations/world.who.html), and population forecast data were obtained from the GBD Global Fertility, Mortality, Migration, and Population Forecasts for 2017–2100 [32]. The "BAPC" R package was used to implement the model, enabling the creation of well-calibrated probabilistic forecasts with relatively narrow uncertainty intervals.

All statistical analyses and mapping were conducted using R software, version 4.2.3 (R Foundation for Statistical Computing), with statistical significance defined as $P<0.05$.

Results

Global, regional, and national burden of overall disorders among AYA

In 2021, there were 643,293,065 prevalent cases of oral disorders reported globally, resulting in a global age-standardized prevalence rate (ASPR) of 34,076.8 (95% uncertainty interval [UI], 34,074.2 to 34,079.4) per 100,000. The total number of DALYs attributed to oral disorders was estimated at 1,711,714 worldwide, with an age-standardized DALY rate (ASDR) of 90.7 (95% UI, 90.5 to 90.8) per 100,000 (Table 1). Among the 21 GBD regions, Andean Latin America reported the highest ASPR and ASDR for oral disorders, at 48,254.2 (95% UI, 48,221.4 to 48,286.9) and 103.8 (95% UI, 102.3 to 105.3) per 100,000, respectively (Table 1, Fig. 1A). At the country level, Paraguay exhibited the highest ASPR at 54,007.6 (95% UI, 53,905.5 to 54,109.8) per 100,000, while Sierra Leone had the highest ASDR, recorded at 158 (95% UI, 153.4 to 162.7) per 100,000 (Figs. 2A and B, Supplementary Table S3).

From 1990 to 2021, the global ASPR of oral disorders decreased by an average of 0.07% per year (95% CI, −0.12 to −0.03), while the ASDR increased by an average of 0.06% per year (95% CI, 0.02 to 0.11; Table 1). Regionally, ASPR significantly declined in most areas, except for four regions: Southern Latin America, which saw an average increase of 0.1% per year (95% CI, 0.04 to 0.16), and South Asia, Australasia, and High-income North America, where rates remained stable (Table 1, Fig. 1B). Similarly, rising ASDRs were noted only in South Asia (EAPC = 0.26 [95% CI, 0.09 to 0.43]) and Southern Latin America (EAPC = 0.07 [95% CI, 0.03 to 0.11]). Across the 204 countries and territories, Colombia exhibited the fastest increase in ASPR (EAPC = 0.7 [95% CI, 0.36 to 1.05]), while Sierra Leone had the most significant rise in ASDR, with an annual increase of 0.82% (95% CI, 0.28 to 1.36; Figs. 2C and D, Supplementary Table S3).

Regional disparities in the burden of four oral disorders among AYA

Globally, the prevalence of caries in permanent teeth, periodontal diseases, edentulism, and other oral disorders among AYA was reported as 578,756,219, 33,880,117, 1,140,860, and 29,252,644 cases, respectively. The corresponding ASPR per 100,000 population were 30,658.1, 1794.7, 60.4, and 1549.6 (Table 1, Fig. 1B). The global DALYs for these conditions among AYA were 579,604 (30.7 per 100,000) for caries of permanent teeth, 225,400 (11.9 per 100,000) for periodontal diseases, 33,152 (1.8 per 100,000) for edentulism, and 861,863 (45.7 per 100,000) for other oral disorders. Notably, these four oral disorders exhibited significantly higher prevalence and DALYs in East Asia (Fig. 3A and B). Caries in permanent teeth accounted for over 80% of all prevalent cases of oral disorders globally and across all GBD regions (Fig. 3C). In contrast, other oral disorders contributed the highest proportion of DALYs globally, followed by caries in permanent teeth, periodontal diseases, and edentulism (Fig. 3D). In 2021, Andean Latin America reported the highest ASPR and ASDR per 100,000 population for caries in permanent teeth, at 45,607.2 and 45.7, respectively. Western Sub-Saharan Africa had the highest rates for periodontal diseases, with an ASPR of 3733.9 and an ASDR of 24.9, while Southern Sub-Saharan Africa recorded the highest rates for edentulism, with an ASPR of 597.7 and an ASDR of 17.3 (Fig. 1A, Supplementary Table S4-S6). Additionally, the burden of other

Table 1 Prevalence and Disability-adjusted life years (DALYs) of oral diseases among adolescent and young adult (10–24 years old) in 1990 and 2021, and their estimated annual percentage changes from 1990 to 2021

Characteristics	Prevalence					DALYs				
	Number of cases in 1990 (Million)	Age-standardized rate per 100,000 population, 1990	Number of cases in 2021 (Million)	Age-standardized rate per 100,000 population, 2021	Estimated annual percentage change, 1990–2021	Number of cases in 1990 (Thousand)	Age-standardized rate per 100,000 population, 1990	Number of cases in 2021 (Thousand)	Age-standardized rate per 100,000 population, 2021	Estimated annual percentage change, 1990–2021
Global	549.17	35,469 (35,466 to 35,471.9)	643.29	34,076.8 (34,074.2 to 34,079.4)	−0.07 (−0.12 to −0.03)	1400.53	90.3 (90.1 to 90.4)	1711.71	90.7 (90.5 to 90.8)	0.06 (0.02 to 0.11)
Sex										
Female	274.42	35,998.5 (35,994.2 to 36,002.8)	317.91	34,506.8 (34,503 to 34,510.6)	−0.09 (−0.14 to −0.04)	720.99	94.3 (94.1 to 94.5)	871.67	94.5 (94.3 to 94.7)	0.05 (0.01 to 0.09)
Male	274.75	34,956.4 (34,952.3 to 34,960.5)	325.38	33,667.8 (33,664.2 to 33,671.5)	−0.06 (−0.11 to −0.01)	679.54	86.4 (86.2 to 86.6)	840.05	87 (86.8 to 87.2)	0.08 (0.03 to 0.12)
Age										
10–14 years	168.7	31,492.9 (21,831.1 to 43,160.6)	188.5	28,276.5 (19,990.5 to 39,064.1)	−0.24 (−0.3 to −0.17)	326.03	60.9 (33.6 to 105.8)	386.51	58 (32.4 to 99.3)	−0.1 (−0.13 to −0.07)
15–19 years	169.44	32,621 (22,828.8 to 44,722.2)	204.16	32,719 (23,558.9 to 43,569.8)	0.07 (0 to 0.13)	448	86.2 (45.4 to 144.1)	545.08	87.4 (47.1 to 146.7)	0.07 (0.03 to 0.1)
20–24 years	211.02	42,883.6 (32,284.2 to 54,395.7)	250.63	41,970.8 (33,125.5 to 52,185.8)	−0.06 (−0.1 to −0.02)	626.5	127.3 (68.7 to 214.2)	780.12	130.6 (71.1 to 216.6)	0.15 (0.09 to 0.2)
Causes										
Caries of permanent teeth	494.54	31,918 (31,915.2 to 31,920.8)	578.76	30,658.1 (30,655.6 to 30,660.6)	−0.07 (−0.12 to −0.01)	495.06	32 (31.9 to 32)	579.6	30.7 (30.6 to 30.8)	−0.06 (−0.12 to −0.01)
Periodontal diseases	24.19	1551.3 (1550.7 to 1551.9)	33.88	1794.7 (1794.1 to 1795.3)	0.4 (0.26 to 0.54)	161.24	10.3 (10.3 to 10.4)	225.4	11.9 (11.9 to 12)	0.4 (0.26 to 0.54)
Edentulism	0.8	51.2 (51.1 to 51.3)	1.14	60.4 (60.3 to 60.5)	1.99 (1.19 to 2.8)	23.12	1.5 (1.5 to 1.5)	33.15	1.8 (1.7 to 1.8)	2 (1.2 to 2.8)
Other oral disorders	24.06	1550.9 (1550.3 to 1551.6)	29.25	1549.6 (1549 to 1550.1)	−0.01 (−0.01 to −0.01)	708.68	45.7 (45.6 to 45.8)	861.86	45.7 (45.6 to 45.8)	0 (−0.01 to 0)
Socio-demographic index										
High	63.52	32,107 (32,099 to 32,114.9)	55.4	29,486.5 (29,478.7 to 29,494.3)	−0.25 (−0.34 to −0.16)	165.15	82.3 (81.9 to 82.7)	149.34	78.7 (78.3 to 79.1)	−0.15 (−0.2 to −0.1)

Table 1 (continued)

Characteristics	Prevalence					DALYs				
	Number of cases in 1990 (Million)	Age-standardized rate per 100,000 population, 1990	Number of cases in 2021 (Million)	Age-standardized rate per 100,000 population, 2021	Estimated annual percentage change, 1990–2021	Number of cases in 1990 (Thousand)	Age-standardized rate per 100,000 population, 1990	Number of cases in 2021 (Thousand)	Age-standardized rate per 100,000 population, 2021	Estimated annual percentage change, 1990–2021
High-middle	100.76	35,285.6 (35,278.6 to 35,292.5)	74.92	33,005.9 (32,998.4 to 33,013.4)	−0.18 (−0.22 to −0.14)	244.86	84.7 (84.4 to 85.1)	189.73	83.3 (83 to 83.7)	−0.02 (−0.04 to 0)
Middle	191.79	34,847.1 (34,842.2 to 34,852.1)	185.29	33,467.5 (33,462.7 to 33,472.3)	−0.07 (−0.13 to 0)	481.38	87 (86.7 to 87.2)	484.1	87.3 (87.1 to 87.6)	0.08 (0.03 to 0.13)
Low-middle	132.48	37,013.5 (37,007.2 to 37,019.8)	193.14	34,925.3 (34,920.4 to 34,930.2)	−0.06 (−0.17 to 0.06)	346.43	98.2 (97.9 to 98.5)	532.81	96.3 (96 to 96.5)	0.05 (−0.04 to 0.14)
Low	60.03	39,294.5 (39,284.5 to 39,304.5)	133.98	36,779.7 (36,773.4 to 36,785.9)	−0.26 (−0.31 to −0.2)	161.4	108.5 (107.9 to 109)	354.45	98.8 (98.4 to 99.1)	−0.34 (−0.39 to −0.29)
GBD regions										
High-income Asia Pacific	11.61	27,303.2 (27,287.5 to 27,319)	6.54	24,550.7 (24,531.8 to 24,569.7)	−0.24 (−0.31 to −0.17)	31.82	74.2 (73.4 to 75)	19.22	71.5 (70.5 to 72.5)	−0.09 (−0.11 to −0.07)
Central Asia	8.33	42,182.1 (42,153.5 to 42,210.8)	9.02	40,855.9 (40,829.2 to 40,882.6)	−0.08 (−0.13 to −0.03)	18.37	93.4 (92.1 to 94.8)	20.11	91.4 (90.2 to 92.7)	−0.06 (−0.09 to −0.04)
East Asia	113.85	29,961.2 (29,955.6 to 29,966.7)	65.57	27,073.9 (27,067.3 to 27,080.5)	−0.24 (−0.34 to −0.14)	298.62	77.5 (77.2 to 77.8)	180.84	74.8 (74.4 to 75.1)	−0.07 (−0.11 to −0.02)
South Asia	121.49	36,664.6 (36,658 to 36,671.1)	187.95	35,566.5 (35,561.5 to 35,571.6)	0.13 (−0.07 to 0.33)	322.35	98.4 (98.1 to 98.8)	525.52	98.9 (98.6 to 99.2)	0.26 (0.09 to 0.43)
Southeast Asia	55.28	37,364 (37,354.1 to 37,373.9)	59.59	34,750.8 (34,741.9 to 34,759.6)	−0.28 (−0.34 to −0.23)	130.67	88.9 (88.4 to 89.4)	146.31	84.9 (84.5 to 85.3)	−0.19 (−0.23 to −0.16)
Australasia	1.65	33,875.9 (33,824.2 to 33,927.8)	1.85	31,973.4 (31,927.3 to 32,019.6)	0.05 (−0.13 to 0.23)	4.09	83.3 (80.8 to 85.9)	4.74	81.3 (79 to 83.7)	0.05 (−0.04 to 0.13)
Caribbean	4.5	42,075.8 (42,036.9 to 42,114.7)	4.47	39,167 (39,130.6 to 39,203.3)	−0.16 (−0.19 to −0.13)	10.7	99.4 (97.5 to 101.3)	10.83	94.3 (92.5 to 96.1)	−0.15 (−0.17 to −0.12)

Table 1 (continued)

Characteristics	Prevalence					DALYs				
	Number of cases in 1990 (Million)	Age-standardized rate per 100,000 population, 1990	Number of cases in 2021 (Million)	Age-standardized rate per 100,000 population, 2021	Estimated annual percentage change, 1990–2021	Number of cases in 1990 (Thousand)	Age-standardized rate per 100,000 population, 1990	Number of cases in 2021 (Thousand)	Age-standardized rate per 100,000 population, 2021	Estimated annual percentage change, 1990–2021
Central Europe	14.13	48,490.7 (48,465.4 to 48,516)	7.6	41,760.4 (41,730.7 to 41,790.1)	−0.39 (−0.43 to −0.35)	29.01	99.9 (98.7 to 101)	17	93.1 (91.7 to 94.5)	−0.18 (−0.2 to −0.16)
Eastern Europe	17.19	36,400.3 (36,383.1 to 36,417.5)	11.23	34,211.5 (34,191.5 to 34,231.6)	−0.21 (−0.28 to −0.13)	41.61	88 (87.2 to 88.9)	27.75	85.2 (84.2 to 86.2)	−0.11 (−0.14 to −0.08)
Western Europe	31.61	38,137.6 (38,124.2 to 38,151)	24.36	33,574 (33,560.6 to 33,587.3)	−0.56 (−0.61 to −0.51)	77.63	91.3 (90.7 to 92)	61.13	83.6 (82.9 to 84.2)	−0.33 (−0.37 to −0.3)
Andean Latin America	6.02	49,089.5 (49,050.3 to 49,128.8)	8.36	48,254.2 (48,221.4 to 48,286.9)	−0.19 (−0.24 to −0.13)	12.66	104.3 (102.5 to 106.2)	18.13	103.8 (102.3 to 105.3)	−0.06 (−0.09 to −0.04)
Central Latin America	18.93	35,184.2 (35,168.3 to 35,200.1)	21.06	32,171.5 (32,157.8 to 32,185.3)	−0.08 (−0.18 to 0.02)	48.85	91.7 (90.9 to 92.5)	58.36	88.7 (88 to 89.4)	−0.02 (−0.07 to 0.03)
Southern Latin America	5.66	42,850.5 (42,815.2 to 42,885.8)	6.57	42,611.1 (42,578.4 to 42,643.7)	0.1 (0.04 to 0.16)	12.58	95.7 (94 to 97.4)	15.02	96.4 (94.9 to 98)	0.07 (0.03 to 0.11)
Tropical Latin America	17.4	36,492.7 (36,475.5 to 36,509.8)	18.12	35,475.9 (35,459.5 to 35,492.3)	−0.15 (−0.24 to −0.07)	41.71	88.1 (87.3 to 89)	45.74	88.3 (87.5 to 89.1)	−0.04 (−0.13 to 0.05)
North Africa and Middle East	45.02	41,611.6 (41,599.4 to 41,623.8)	63.26	39,060 (39,050.3 to 39,069.6)	−0.29 (−0.34 to −0.24)	100.62	94.2 (93.7 to 94.8)	149.37	92.6 (92.1 to 93)	−0.08 (−0.11 to −0.05)
High-income North America	17.79	28,813.2 (28,799.8 to 28,826.7)	18.47	25,627.7 (25,616 to 25,639.4)	0.03 (−0.27 to 0.33)	48.06	76.8 (76.1 to 77.5)	53.59	73.9 (73.2 to 74.5)	−0.04 (−0.17 to 0.08)
Oceania	0.98	47,081.8 (46,988.5 to 47,175.3)	1.87	46,465.9 (46,399.3 to 46,532.6)	−0.04 (−0.06 to −0.02)	1.97	95.4 (91.2 to 99.7)	3.7	92.2 (89.2 to 95.2)	−0.15 (−0.17 to −0.12)
Central Sub-Saharan Africa	6.31	37,235.9 (37,206.8 to 37,265.1)	15.35	35,039.8 (35,022.1 to 35,057.4)	−0.28 (−0.34 to −0.22)	18.07	108.9 (107.3 to 110.5)	40.86	94.7 (93.8 to 95.6)	−0.62 (−0.73 to −0.52)

Table 1 (continued)

Characteristics	Prevalence					DALYs				
	Number of cases in 1990 (Million)	Age-standardized rate per 100,000 population, 1990	Number of cases in 2021 (Million)	Age-standardized rate per 100,000 population, 2021	Estimated annual percentage change, 1990–2021	Number of cases in 1990 (Thousand)	Age-standardized rate per 100,000 population, 1990	Number of cases in 2021 (Thousand)	Age-standardized rate per 100,000 population, 2021	Estimated annual percentage change, 1990–2021
Eastern Sub-Saharan Africa	24.51	40,304.6 (40,288.5 to 40,320.7)	52.5	36,560.8 (36,550.9 to 36,570.7)	−0.43 (−0.47 to −0.38)	63.83	108 (107.2 to 108.9)	133.35	94.1 (93.6 to 94.6)	−0.57 (−0.63 to −0.51)
Southern Sub-Saharan Africa	4.99	29,669.3 (29,643.2 to 29,695.4)	6.47	29,795.7 (29,772.7 to 29,818.6)	−0.08 (−0.21 to 0.05)	15.87	95.5 (94 to 97)	20.24	93.6 (92.3 to 94.9)	−0.1 (−0.37 to 0.16)
Western Sub-Saharan Africa	21.92	37,496.6 (37,480.8 to 37,512.4)	53.08	33,634 (33,624.9 to 33,643.1)	−0.45 (−0.49 to −0.41)	71.46	125.5 (124.6 to 126.5)	159.92	103.5 (102.9 to 104)	−0.79 (−0.86 to −0.71)

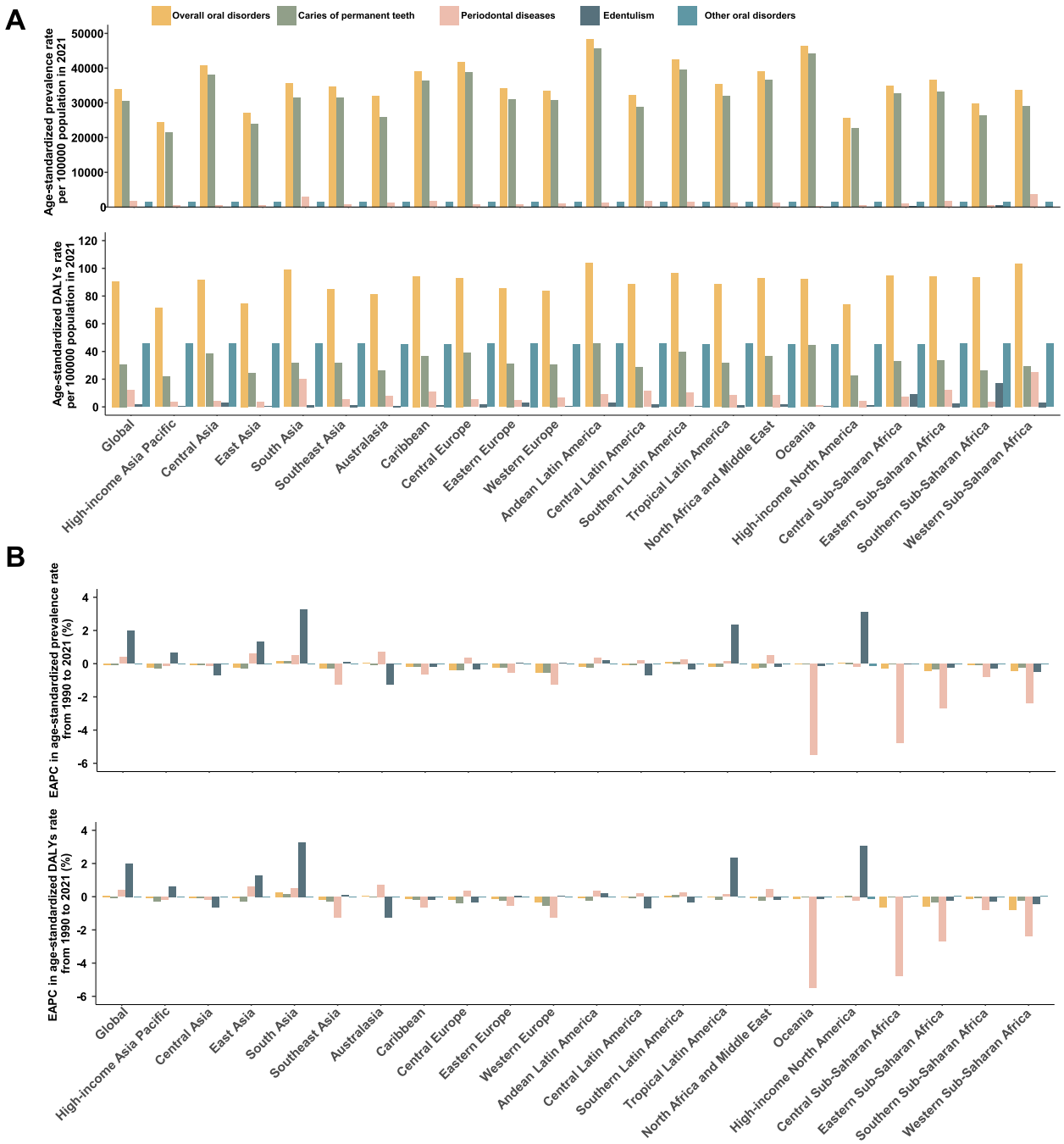

Fig. 1 Age-standardized prevalence and DALY rates in 2021, and their estimated annual percentage changes from 1990 to 2021 for oral diseases among adolescent and young adult, globally and by 21 GBD regions. Age-standardized rates of prevalence and DALYs (**A**), and estimated annual percentage changes of age-standardized rates of prevalence and DALYs (**B**). Oral diseases include caries of permanent teeth, periodontal diseases, edentulism, and other oral disorders. DALY = Disability-adjusted life-years; EAPC = estimated annual percentage change

oral disorders was relatively consistent across all 21GBD regions (Fig. 1A, Supplementary Table S7).

Between 1990 and 2021, the global ASPR and ASDR significantly decreased for caries in permanent teeth significantly decreased, with EAPC of –0.07 and –0.06, respectively. In contrast, the rates for other oral disorders remained stable, with EAPCs of –0.01 and 0. Notably, there was a significant upward trend for periodontal diseases (EAPC = 0.4) and edentulism (EAPC = 2.0; Table 1). In the context of the 21 GBD regions, the

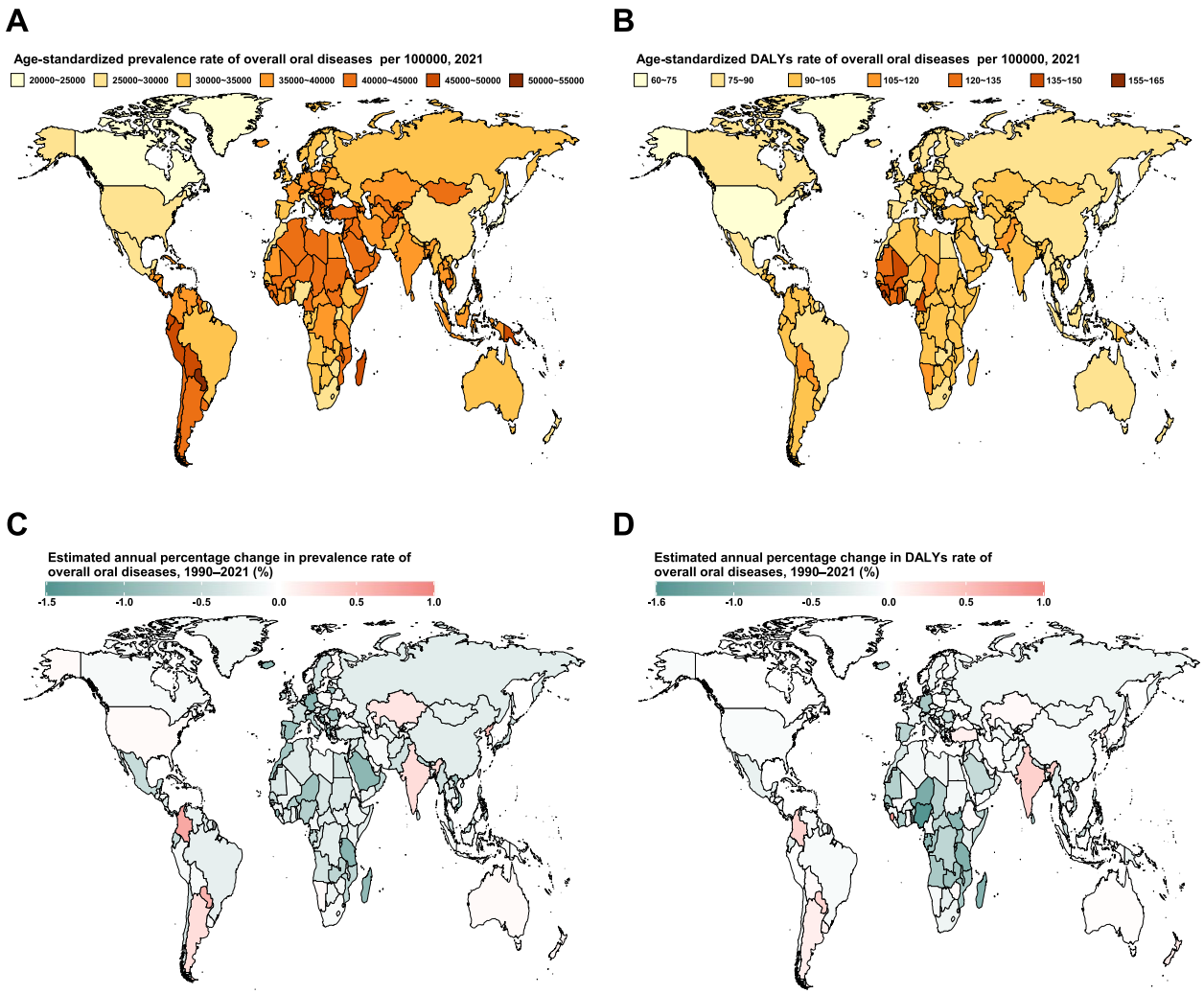

Fig. 2 Age-standardized prevalence and DALY rates in 2021, and their estimated annual percentage changes from 1990 to 2021 for overall oral diseases among adolescent and young adult, across 204 countries and territories. Age-standardized rates of prevalence (**A**) and DALYs (**B**). Estimated annual percentage changes of age-standardized prevalence rate (**C**) and DALY rate (**D**). Oral diseases include caries of permanent teeth, periodontal diseases, edentulism, and other oral disorders. DALY = Disability-adjusted life-years

ASPR increased in 1, 9, and 6 regions for caries in permanent teeth, periodontal diseases, and edentulism, respectively. The highest increases were observed in Southern Latin America (EAPC = 0.11), Australasia (EAPC = 0.73), and South Asia (EAPC = 3.25). The patterns of change in the ASDR closely mirrored those of the ASPR (Fig. 1B, Supplementary Table S4-S6).

At the national level in 2021, the highest ASPR and ASDR per 100,000 population for caries in permanent teeth were reported in Paraguay (51,612.3 and 51.6, respectively). For periodontal diseases, Sierra Leone had the highest rates (11,287.1 and 75.1), while Namibia led in edentulism rates (1020.5 and 29.6). From 1990 to 2021, the most significant increases in both ASPR and ASDR for caries of permanent teeth were observed in Colombia, while Sierra Leone saw the highest increases for periodontal diseases, and Sweden for edentulism (Supplementary Figure S1-S3, Table S8-S10). In terms of other oral disorders, Nigeria had the highest ASPR at 1564.1 per 100,000, and China reported the highest ASDR at 45.99 per 100,000. During the same period, the Syrian Arab Republic experienced the fastest annual increase in ASPR at 0.03%, while the United Republic of Tanzania recorded the fastest annual increase in ASDR at 0.04% (Supplementary Figure S4, Table S11).

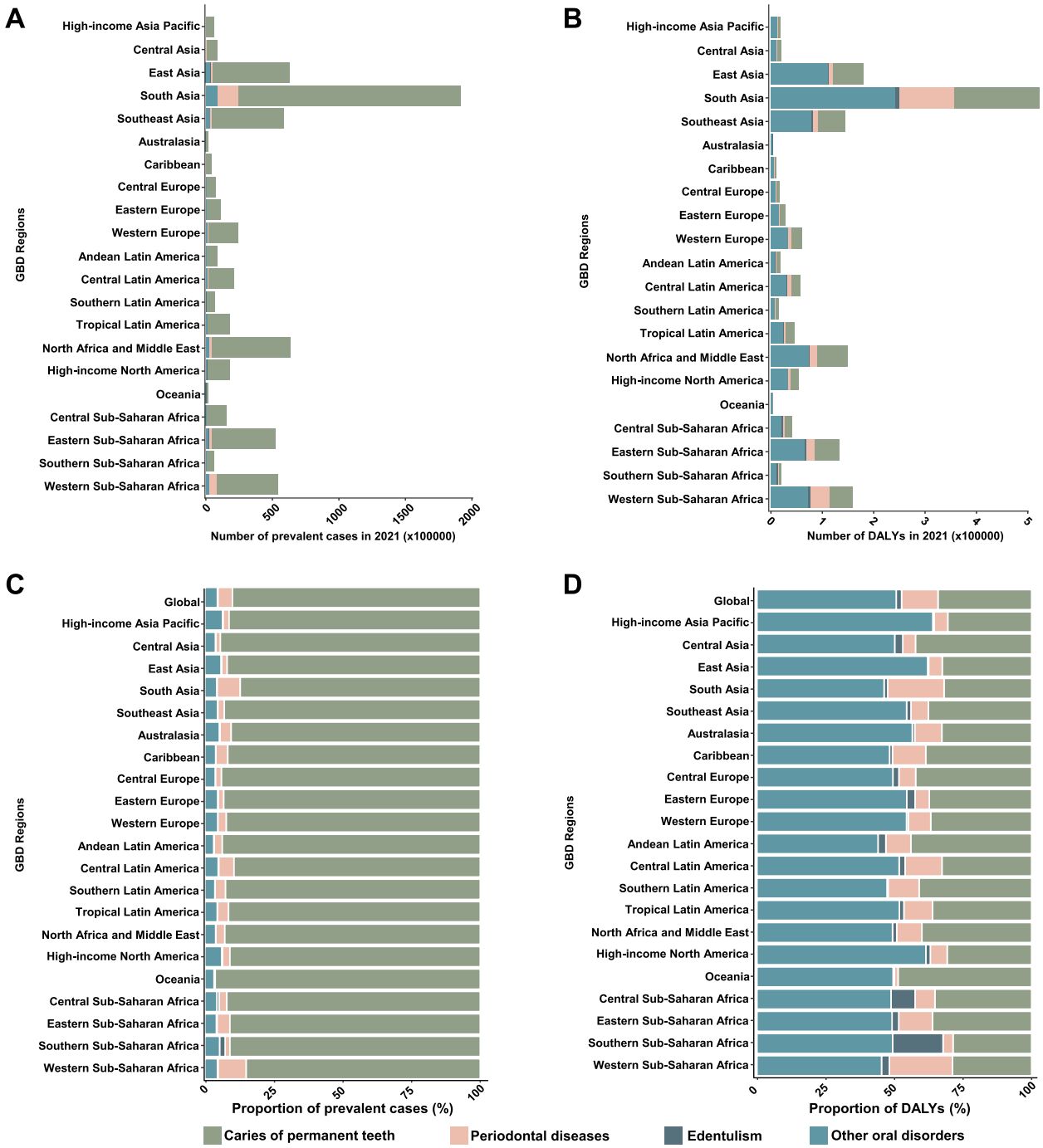

Fig. 3 Numbers and proportions of prevalent cases and DALYs contributed by 21 GBD regions, for oral diseases among adolescent and young adult, in 2021. Numbers of prevalent cases (**A**) and DALYs (**B**) of each oral disease. Proportions of prevalent cases (**C**) and DALYs (**D**) accounted for by each oral disease. Oral diseases include caries of permanent teeth, periodontal diseases, edentulism, and other oral disorders.
DALY = Disability-adjusted life-years

The association between ASR, EAPC, and SDI

From 1990 to 2021, across the 21 GBD regions, the overall ASPR of oral disorders initially remained stable as the SDI increased but began to decline around an SDI of 70. In contrast, the overall ASDR decreased exponentially with increasing SDI (Supplementary Figure S5). For caries in permanent teeth, both ASPR and ASDR initially rose before declining at an SDI of 70.

Meanwhile, the ASPR and ASDR for periodontal diseases decreased exponentially with rising SDI. In comparison, the ASPR and ASDR for edentulism and other oral disorders decreased more gradually with increasing SDI (Fig. 4).

In terms of the 204 countries and territories in 2021, both the ASPR and ASDR for overall oral disorders, as well as for each specific oral disorder, decreased with rising SDI (Supplementary Figure S6-S10). Additionally, countries with higher SDI levels experienced a faster annual increase in the ASDR for caries in permanent teeth, as well as in the ASPR and ASDR for periodontal diseases from 1990 to 2021 (Supplementary Figure S6-S10). Furthermore, negative associations were observed between the estimated annual percentage changes (EAPCs) of ASPR or ASDR and SDI for overall oral disorders and edentulism from 1990 to 2021, while a positive association was noted between the EAPCs of ASDR for other oral disorders and SDI during the same period (Fig. 5).

From 1990 to 2021, the ASPR of overall oral disorders increased only in individuals aged 15–19 years in regions with a middle SDI. In contrast, the ASDR for overall oral disorders rose among individuals aged 15–19 and 20–24 years in the same regions. Notably, both the ASPR and ASDR for overall oral disorders declined across all three age groups in high- and low-SDI regions (Supplementary Figure S11).

Projected ASPR of overall oral disorders among AYA through 2040

According to projections for the ASPR of overall oral disorders globally and across 21 GBD regions, a decline is expected between 2021 and 2040 in most regions, except for Tropical Latin America and Oceania. Globally, the ASPR is anticipated to decrease from 34,076.8 per 100,000 population in 2021 to 28,462.4 per 100,000 population in 2040. In contrast, the ASPR is expected to rise to 38,579.8 per 100,000 population in Tropical Latin America and 47,172.6 per 100,000 population in Oceania by 2040 (Fig. 6).

Discussion

To the best of our knowledge, this is the first comprehensive analysis of the global landscape, temporal trends, and regional variations in the prevalence and DALYs of oral disorders among AYA from 1990 to 2021, as well as their association with socioeconomic status at both regional and national levels, using data from the GBD 2021. Our findings reveal that from 1990 to 2019, the global ASPR of oral disorders declined by an average of 0.07% per year, while the ASDR increased by 0.06% annually. At the same time, the global absolute number of prevalent cases and DALYs for oral disorders rose by 17.1% and 22.2%, respectively, over the same period. Notably, both ASPR and ASDR showed consistent annual increases in periodontal diseases and edentulism worldwide. Significant regional disparities were observed in the prevalence and DALYs of oral disorders, with the most rapid increases in ASPR and ASDR occurring in Southern Latin America and South Asia, respectively. Furthermore, we found a negative association between ASPR and ASDR for oral disorders and the SDI at both regional and national levels.

Our findings suggest that the global decline in the ASPR of oral disorders among AYA between 1990 and 2021 can largely be attributed to the reduction in dental caries of permanent teeth. Dental caries is a complex, multifactorial disease driven by biofilm formation and sugar consumption, which leads to the demineralization and remineralization of tooth structures, causing substantial economic and quality-of-life burdens [33]. Therefore, reducing the impact of dental caries is especially important during youth. A better understanding of its prevalence at regional and national levels is crucial for improving access to effective oral care. The global decline in caries prevalence is largely linked to improvements in oral hygiene, dietary changes, and public health interventions, particularly the increased use of fluoride [34]. One of the key factors contributing to this decline is the widespread adoption of regular tooth brushing, especially with fluoride toothpaste. Additionally, advances in antimicrobial dental materials that release agents, kill bacteria on contact, or combine multiple strategies have helped prevent initial bacterial attachment and biofilm formation [35]. The introduction of fluoridation in public water supplies has also been one of the most effective public health measures for reducing dental caries [36]. Moreover, there has been a global shift toward reduced sugar consumption, driven by health campaigns, dietary changes, and policy interventions such as sugar taxes and food labeling regulations [37]. This reduction in sugary snacks, sodas, and processed foods has led to fewer acid attacks on teeth and less biofilm formation, further contributing to lower caries rates. However, despite these gains, dental caries remains a major oral health challenge, particularly among AYA, and continues to account for more than three-quarters of prevalent oral disorders in this age group. To more effectively mitigate the burden of dental caries in AYA, a multi-faceted approach is essential. This should include enhanced surveillance, improved preventive strategies, expanded access to dental care, and behavioral interventions. Focusing on high-risk groups, increasing access to fluoride treatments, promoting healthier diets, and leveraging new technologies can all help reduce caries prevalence and prevent its

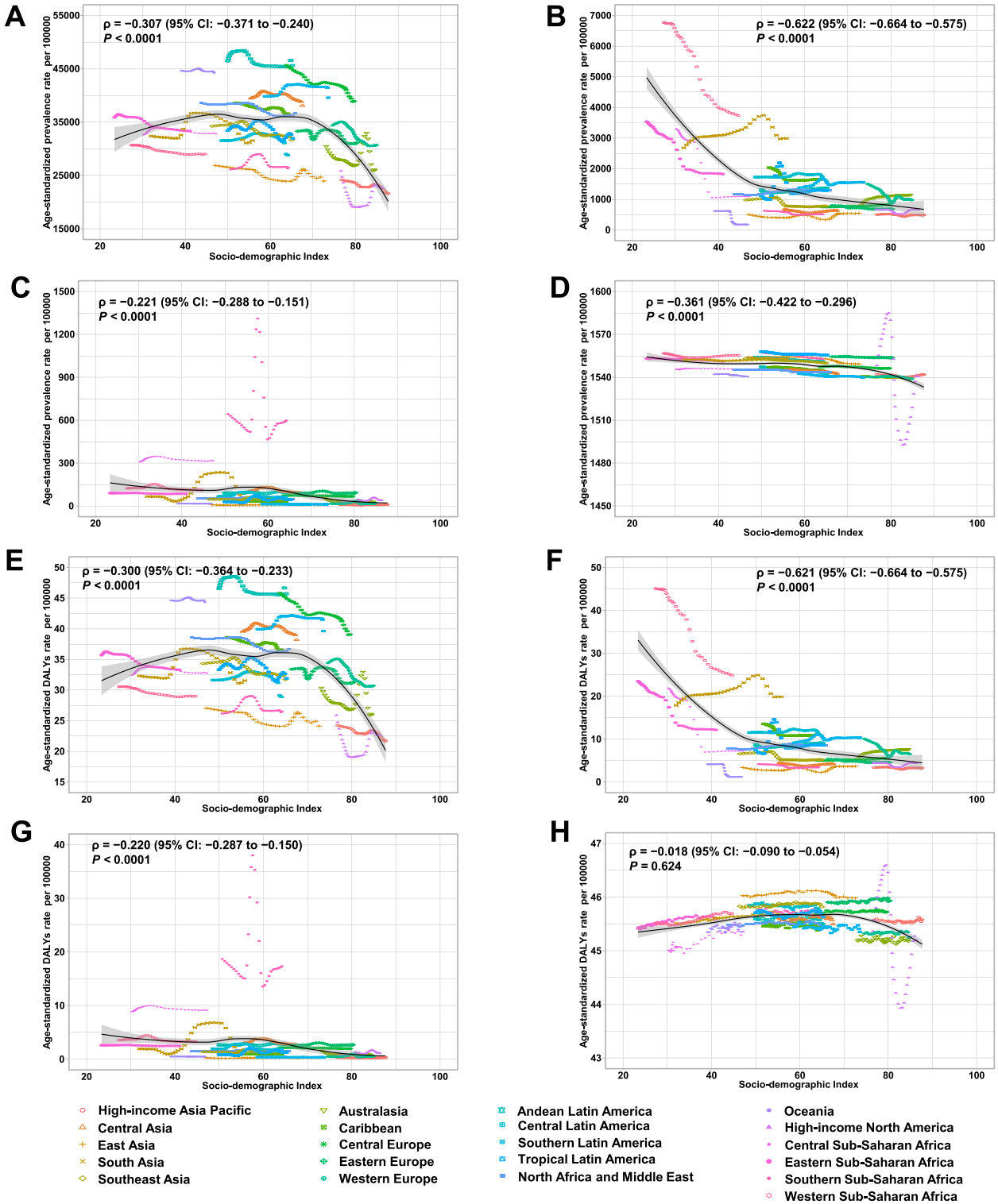

Fig. 4 Age-standardized rates of prevalence and DALYs of each oral disease among adolescent and young adult, globally and for 21 GBD regions, by socio-demographic index (SDI), from 1990 to 2021. Age-standardized prevalence rates of caries of permanent teeth (**A**), periodontal diseases (**B**), edentulism (**C**), and other oral disorders (**D**), by SDI. Age-standardized DALY rates of caries of permanent teeth (**E**), periodontal diseases (**F**), edentulism (**G**), and other oral disorders (**H**), by SDI. Expected values with 95% CI, based on SDI and disease rates in all locations, are shown as a solid line and shaded area; 32 points are plotted for each region and show the observed age-standardized prevalence or DALY rates for each year from 1990 to 2021. Points above the solid line represent a higher-than-expected burden, and those below the line show a lower-than-expected burden. DALY = Disability-adjusted life-years; GBD = Global Burden of Diseases Study

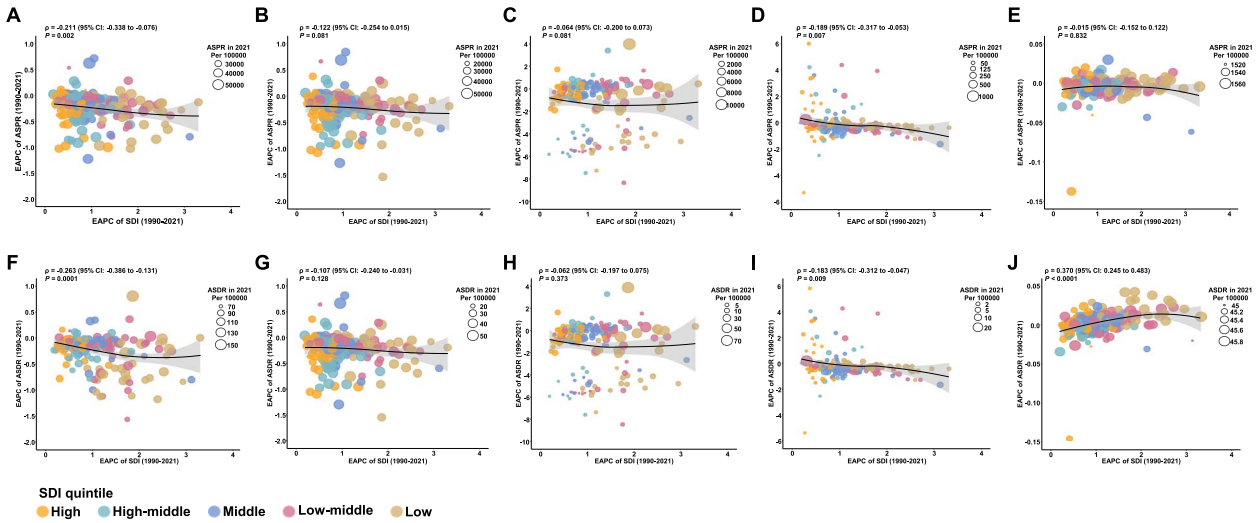

Fig. 5 The association between the estimated annual percentage change in age-standardized rates of prevalence or DALYs for oral diseases and the estimated annual percentage change in socio-demographic index (SDI), for the 204 countries and territories, 1990–2021. The estimated annual percentage change in age-standardized prevalence rate of overall oral disorders (**A**), caries of permanent teeth (**B**), periodontal diseases (**C**), edentulism (**D**), and other oral disorders (**E**) among adolescent and young adult. The estimated annual percentage change in age-standardized DALYs rate of overall oral disorders (**F**), caries of permanent teeth (**G**), periodontal diseases (**H**), edentulism (**I**), and other oral disorders (**J**) among adolescent and young adult. DALY = disability-adjusted life-years. EAPC = estimated annual percentage change

long-term consequences. By incorporating these efforts into broader public health strategies, we can improve oral health outcomes and reduce the overall impact of dental caries on this vulnerable age group.

The global ASPR of oral disorders has shown a slight decline over the past three decades; however, the ASDR has paradoxically increased, indicating that while the overall prevalence of oral diseases may be decreasing in certain contexts, their severity and consequences on AYA health are intensifying. These trends highlight the growing impact of oral diseases, particularly in regions with a middle SDI. The decline of ASPR can be attributed to several public health improvements, including better oral hygiene practices, fluoride use, dietary changes, and preventive programs. The increase in ASDR may be due to an increasing burden of more severe oral conditions, such as periodontal diseases and edentulism, which are less amenable to simple prevention measures like fluoride use and require more complex long-term care. Notably, the burden of both periodontitis and edentulism has unexpectedly risen among AYA globally from 1990 to 2021. Smoking is one of the most significant risk factors for periodontitis, with higher smoking rates correlating with increased incidences of periodontal disease [38]. Smoking weakens the immune system, impairs blood flow to the gums, and fosters the growth of harmful oral bacteria, all of which accelerate periodontal destruction. Despite substantial public health efforts to reduce cigarette smoking among youth, an estimated 155 million individuals aged 15–24 were tobacco smokers globally in 2019 [39]. Of these, 65.5% of AYA reported starting smoking before the age of 20. Smoking rates exceed 20% among males aged 15–24 in 120 countries and among females in 43 countries. The rise of e-cigarette use as an alternative to traditional tobacco products presents new risks to oral health [40]. Though research is ongoing, evidence suggests that e-cigarettes may contribute to gum inflammation and exacerbate periodontal disease over time [41]. In addition, lifestyle transitions have led to a decrease in physical activity and an increase in obesity among AYA, a growing public health concern in recent decades [42, 43]. The COVID-19 pandemic, with its associated lockdowns, social distancing, and closure of gyms and schools, forced many young people into more sedentary lifestyles, contributing to lower levels of physical activity and higher obesity rates [44]. This shift to more screen-based activities, including online learning, has further exacerbated the risk of obesity. Increasing evidence links obesity with a higher risk of periodontal disease, as obesity-induced inflammation disrupts the oral microbiome, promoting periodontal deterioration [45]. The rising prevalence of metabolic diseases in AYA, including obesity, type 2 diabetes, and metabolic syndrome, further elevates the risk of periodontitis [46, 47]. Conversely, periodontitis can worsen the management of these metabolic conditions, creating a bidirectional relationship that underscores the importance of managing both oral and systemic health in young individuals with

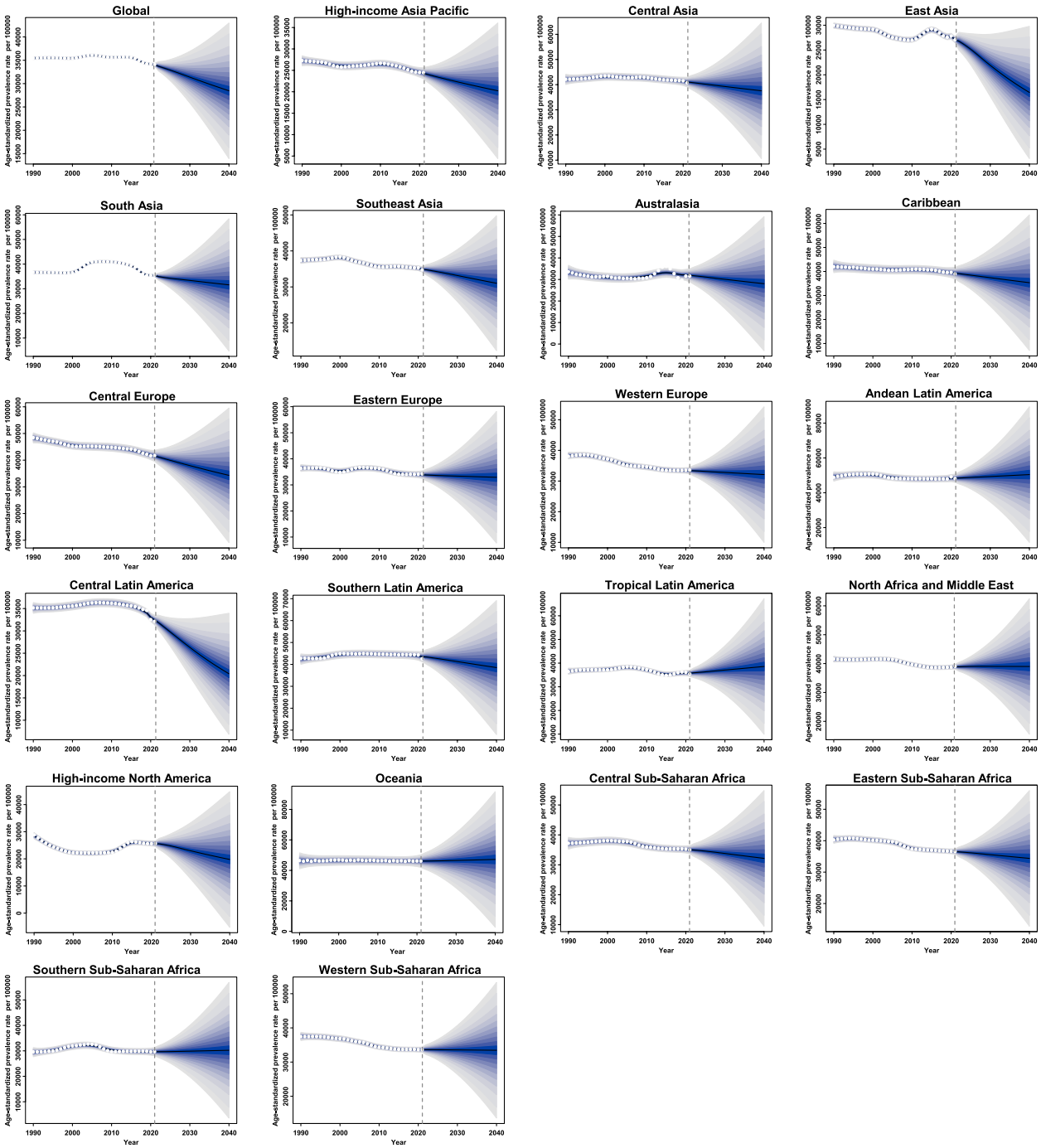

Fig. 6 Temporal trends in the age-standardized prevalence rate of oral diseases among adolescent and young adult from 1990 to 2021, with projections through 2040, globally and for 21 GBD regions. The blue shaded area represents the 95% uncertainty interval (UI), illustrating the upper and lower bounds

metabolic disorders [47]. Edentulism, which often results from advanced periodontitis, is a consequence of severe periodontal disease [48]. While tooth loss is less common among AYA than older populations, the increasing prevalence of periodontitis in younger groups has contributed to a rise in edentulism. As periodontitis progresses, it can cause significant gum damage and bone loss, leading to tooth loss that cannot be restored.

These conditions are more complex and severe than dental caries and are associated with significant

functional and aesthetic impacts, often leading to permanent tooth loss (edentulism) or long-term damage to oral structures (periodontitis). Periodontal disease, in particular, has been linked to risk factors such as smoking, obesity, and metabolic diseases, which are increasingly prevalent among AYA globally. Despite substantial progress in controlling caries, periodontal disease often worsens with lifestyle changes (e.g., increased tobacco and alcohol consumption) and chronic systemic conditions, which contribute to its severity and, therefore, its disability impact. Addressing this concerning trend requires comprehensive strategies that focus on early detection, improved oral health education, greater access to preventive care, and better management of risk factors such as smoking, diet, and physical inactivity. By adopting a multi-faceted approach to the prevention and management of periodontal disease, we can effectively reduce the burden of periodontitis and edentulism among AYA.

In general, the burden of oral disorders among AYA tends to decrease with higher SDI, but regions with lower SDI experience a faster annual percentage decrease in the ASDR for oral disorders. This disparity has been extensively documented in previous studies, which have highlighted the causal relationships between socioeconomic status and oral health outcomes [1]. While regions with lower SDI start at a disadvantage due to limited access to quality dental care, they often see more rapid improvements in oral health as healthcare systems develop. Even modest advancements, such as the introduction of basic preventive measures, can lead to substantial reductions in oral health burdens in these regions [49]. In these settings, small improvements can have a disproportionately large effect, resulting in a faster decline in ASDR, despite the overall burden remaining higher compared to high-SDI regions. Additionally, regions with lower SDI are typically in earlier stages of the epidemiological transition, where the burden of infectious diseases and preventable oral disorders is more pronounced. As these regions progress through the transition, improvements in basic healthcare infrastructure and increased access to dental care often led to rapid declines in oral disease incidence [13]. For example, as the burden of untreated dental caries and periodontal disease decreases due to better oral hygiene practices and expanded dental services, the annual rate of decline in ASDR accelerates. In contrast, regions with higher SDI have usually already passed through the initial stages of the epidemiological transition. In these areas, the burden of chronic oral diseases, such as periodontitis and edentulism, may be increasing, as these conditions are more complex and require ongoing management. These diseases are often linked to risk factors such as smoking, diabetes, and obesity. As a result, improvements in ASDR are less pronounced in high-SDI regions because the population has already benefited from basic interventions, and the focus shifts to managing more complex and persistent oral health issues [11].

Our findings reveal significant regional disparities in the prevalence and DALYs of oral diseases, underscoring the urgent need for targeted public health interventions. Looking ahead, our projections suggest a continued global decline in the ASPR for oral disorders through 2040, with notable exceptions in Tropical Latin America and Oceania. The rising burden of oral disorders in these regions can be attributed to several factors, including limited access to dental care, dietary shifts, increasing tobacco use, insufficient public health programs, and environmental influences [39]. Additionally, the rapid urbanization and adoption of Westernized lifestyles, combined with escalating rates of obesity and chronic diseases like diabetes, are further driving the growing prevalence of oral disorders [50, 51]. The anticipated rise in oral disease burdens in these regions signals potential public health challenges that require proactive strategies. This highlights the importance of closely monitoring trends and tailoring interventions to local contexts, ensuring that they effectively address emerging health needs and evolving risk factors.

Regions like Andean Latin America and certain areas of Sub-Saharan Africa have high age-standardized prevalence rates (ASPR) of oral disorders. To address these challenges, we recommend implementing more comprehensive preventive measures in these high-risk areas, including: integrating educational campaigns into school curricula and community-based health programs, expanding fluoride initiatives, introducing policies such as sugar taxes and clearer food labeling to regulate the marketing of sugary products, and improving access to affordable dental care. Additionally, the rising prevalence of periodontal diseases among AYAs, especially in regions like South Asia and Southern Latin America, warrants targeted action. Increased screening and early diagnosis of periodontal diseases in high-risk populations are critical for enabling timely interventions and preventing long-term complications such as tooth loss. Our study also underscores the significant impact of socioeconomic factors on oral health outcomes. Therefore, policies addressing the broader social determinants of health are essential for improving oral health among AYAs. To enhance future data on the burden of oral diseases and assess the effectiveness of interventions, we recommend strengthening oral health surveillance systems to provide more accurate and timely data on the prevalence and severity of oral diseases in AYAs.

To effectively reduce the growing burden of oral diseases among AYA, we propose a comprehensive,

multi-pronged strategy that combines public health initiatives, policy measures, and targeted prevention efforts. These strategies include: (1) Implementing school-based programs, such as supervised toothbrushing and oral health education, to effectively engage AYA. (2) Strengthening regulations on tobacco and e-cigarette advertising, increasing taxation on tobacco products, and launching awareness campaigns to discourage youth smoking. (3) Introducing sugar taxes, improving food labeling policies, and restricting the marketing of sugary beverages and snacks to younger populations. (4) Expanding insurance coverage for preventive dental care and integrating oral health services into primary healthcare systems to facilitate early intervention and curb the progression of severe oral diseases. (5) Promoting physical activity and healthy nutrition programs to mitigate metabolic disorders associated with poor oral health. (6) Strengthening data collection and monitoring systems to track emerging trends in oral diseases and inform targeted interventions.

Nevertheless, the current study has several limitations. First, the accuracy and robustness of the estimates for the prevalence and DALYs of oral disorders were constrained by the availability and quality of data, which could lead to biases, particularly in regions where national surveillance or population-based studies are lacking. To mitigate this, various adjusted methods, including misclassification corrections and redistribution of garbage codes, were employed to reduce bias. Second, the study relies on aggregated data at the national and regional levels, which may obscure local variations in oral health outcomes. Third, the use of annual percentage changes to assess long-term trends from 1990 to 2021 may have overlooked recent short-term shifts that could reflect the effectiveness of prevention interventions. Fourthly, while the projections of future trends suggest a continued global decline in the ASPR for oral disorders, these projections are based on current trends and assumptions, which may not fully account for potential future changes in public health policies, technological advances, or unexpected events that could impact oral health outcomes. Lastly, while our age stratification (10–14, 15–19, 20–24 years) aligns with the WHO adolescent health framework for policy relevance, we acknowledge that significant biological and physiological variations within the 10–24 age range may impact oral health outcomes. Each subgroup exhibits biological heterogeneity, such as the transition from mixed to full permanent dentition (10–14 vs. 20–24 years) [52], variations in tooth eruption patterns (e.g., third molar emergence in late adolescence) [53], and hormonal changes [54], including puberty-driven shifts in the oral microbiome that may affect susceptibility to caries and periodontitis. However, our observational study design limited the ability to perform more granular age-stratified analyses. Additionally, the cross-sectional nature of the GBD data restricts causal inference between age-related biological changes and oral disease trajectories.

Conclusion

In conclusion, between 1990 and 2021, the ASPR of oral disorders among AYA gradually declined, while the ASDR increased. Oral disorders continue to be a significant concern for AYA across both high- and low-resource countries. Therefore, global efforts to reduce the burden of oral disorders remain critical.

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12903-025-05864-z.

Supplementary Material 1

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Clinical trial number
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Authors' contributions
Xingzhu Dai: Conceptualization; Methodology; Data curation; Formal analysis; Visualization; Writing – original draft; Writing – review & editing. Manqiong Dai: Methodology; Data curation; Visualization; Writing – original draft; Writing – review & editing. Yuee Liang: Data curation; Visualization; Writing – review & editing. Xiaoyu Li: Data curation; Visualization; Writing – review & editing. Wanghong Zhao: Conceptualization; Project administration; Supervision; Writing – review & editing.

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Data availability
The original contributions presented in the study are included in the article/Supplementary material, further inquiries can be directed to the corresponding author.

Declarations

Ethics approval and consent to participate
This study was conducted in full accordance with the Institute for Health Metrics and Evaluation (IHME) Free-of-Charge Non-commercial User Agreement and Privacy Policy. It is based on publicly available, de-identified data from the Global Burden of Disease (GBD) Study 2021, which adheres to the ethical principles outlined in the Declaration of Helsinki. As the study did not involve individual-level data or direct human participation, ethical approval and informed consent were not required. The GBD Study has received ethical approval from the Institutional Review Board of the University of Washington.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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