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Trends and inequalities in age-standardized prevalence rate of edentulism among members of European Union between 1990 and 2021

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Abstract

Background Edentulism, or the complete loss of teeth, is a major public health concern, particularly among older and economically disadvantaged populations. It affects masticatory function, nutrition, aesthetics, and psychological well-being, and contributes to social isolation and employment difficulties. This study aimed to assess the age-standardized prevalence rates (ASPR) of edentulism in 28 EU member states from 1990 to 2021, focusing on health inequalities across countries and sexes, and identifying trends and peaks in prevalence.

Methods Data were obtained from the Global Burden of Disease (GBD) 2021 study. ASPR per 100,000 of edentulism was extracted. Inequalities between countries were evaluated using the Gini Coefficient (GC) and Slope Index of Inequality (SII), while ASPR ratios were calculated to compare countries with the highest and lowest prevalence rates. Total percentage change (TPC) was also extracted and reported.

Results The ASPR of edentulism in the EU was 4986 (95% UI: 3996 to 6041) per 100,000 in 1990 and 4441 (95% UI: 3537 to 5387) per 100,000 in 2021. The TPC for the EU population showed significant variation, with Finland exhibiting decreasing prevalence rate of -27.76 (95% UI: -40.74 to -17.23), and Sweden the increased rate at 31.07 (95% UI: -8.84 to 94.22). ASPR ratios for males in 2021 ranged from 1.00 to 2.33, while females had a narrower range, from 1.00 to 2.07. The highest ASPR ratio was observed in 2010 (4.64), while the lowest was recorded in 2018/2019 (1.84), with notable peaks in 2005 (3.10) and 2020/2021 (2.19). The GC for edentulism declined from 0.121 (95% UI: 0.095 to 0.147) in 1990 to 0.104 (95% UI: 0.079 to 0.129) in 2021, with males consistently exhibiting higher GC values. The SII also decreased from 0.075 (95% UI: 0.060 to 0.090) in 1990 to 0.059 (95% UI: 0.046 to 0.071) in 2021, with the highest SII in 2009 (0.102) and the lowest in 2016 (0.052).

Conclusions Despite a reduction in edentulism prevalence and inequalities by 2021 in some countries, significant inequalities remain between member states of the EU. These findings underscore the need for targeted interventions

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and policies to address oral health inequalities, particularly for men, who showed higher levels of inequality compared to women.

Background

Edentulism, characterized by tooth loss, serves as a global indicator of oral health burden, particularly affecting older and economically disadvantaged populations [1]. Associated with pain, speech and eating difficulties, reduced productivity, and a decline in quality of life, edentulism is mostly linked to impaired masticatory function (involved in the process of chewing), nutritional deficiency, aesthetic concerns, and psychological challenges [2, 3]. The repercussions of tooth loss can significantly contribute to chronic temporomandibular pain, impact self-esteem, interfere in social integration, and pose challenges in employment opportunities [4]. Furthermore, edentulism has a significant social impact by causing difficulties in work and school, while also worsening loneliness and social isolation due to the stigma attached to tooth loss [5, 6]. Unlike many other non-communicable diseases (NCDs), edentulism is a definitive condition, representing the ultimate outcome of various dental issues [7]. These include dental caries and trauma, which are highly prevalent in younger individuals, as well as periodontal diseases, which are more commonly found in older populations [8]. Primary causes of edentulism underscore the importance of preventive measures and policies [7]. Individuals at lower economic status are more susceptible to the onset of edentulism, and this condition is highly associated with social inequalities [9]. Edentulism shares several risk factors with NCDs, including smoking, alcohol use, and low socioeconomic status [10, 11].

Despite declining or stabilized age-standardized prevalence rates (ASPR), the absolute disease burden of edentulism has nearly doubled, persisting prominently in regions with a low socio-demographic index [1]. In high-income countries, the absolute number of edentulous individuals is rising due to population aging [12, 13]. However, edentulism in old age is more than just a consequence of the aging process; rather, it is a manifestation of the cumulative impact of oral disease over the years [14]. Socioeconomic factors, such as income, education, oral health knowledge, and attitudes toward dental care, contribute to the prevalence of edentulism [15, 16]. The high prevalence of edentulism worldwide contributes to both direct and indirect economic burden [1]. Beyond this, in 2015, dental diseases imposed a substantial global economic burden, totaling $544.41 billion. Direct treatment costs comprised $356.80 billion, and lost productivity amounted to $187.61 billion. Notably, severe tooth loss contributed to 67% of the productivity losses associated with dental diseases [2].

The fact that edentulism is highly preventable but also highly prevalent and unequal among the global population, emphasizes the lack of prevention policies supporting brushing teeth, flossing, oral health education, regular dental check-ups, sugar reduction policies, fluoridation, and smoking prevention [17–19]. It is crucial to address this condition, and investing in the prevention and treatment of dental caries and periodontal disease may be pivotal in reducing the prevalence of edentulism [20, 21]. While declining disease burden has been observed in some countries, the World Health Organization's goal of retaining at least 20 teeth at the age of 80 years remains unmet in numerous regions [22]. Previous studies have demonstrated different levels of inequalities in NCDs between European countries [23, 24]. The European Union (EU) has acknowledged the significance of oral health in its policy documents, including "An overview of current approaches and opportunities for improvement" [25]. The document stresses the need to monitor and address inequalities in oral health. Health systems are not always able to provide adequate financial protection, which can result in individuals being unable to afford healthcare or meet other basic needs. This can have a negative impact on access to healthcare, lead to or exacerbate poverty, and contribute to the perpetuation of health and socio-economic inequalities [26]. A long tradition of universal policies, welfare and rights-based approaches to health and to the conditions necessary for a healthy lifestyle has been established in Europe. Over the past two decades, however, significant shifts have occurred in policy approaches and commitments which have the potential to exacerbate population health inequality. Nevertheless, new technical and political opportunities are emerging that are supporting efforts to move forward in terms of equity in health and life opportunities. For example, the above mentioned "An overview of current approaches and opportunities for improvement" underscores the necessity for more efficacious instruments to gauge access to healthcare at the European level, encompassing the adaptation of the EU statistics on income and living conditions (EU-SILC) to yield more granular data on obstacles to healthcare access and the cross-linking of the EU-SILC and European health interview survey (EHIS). Consequently, an investigation into the discrepancy in research on the patterns and inequalities in the prevalence of edentulism within the EU can facilitate the formulation of more efficacious policies and interventions with the objective of enhancing oral health and reducing inequalities.

The objective of this study was to present the ASPR of edentulism across the 28 EU member states from 1990 to 2021, encompassing both sexes. This analysis aimed to assess health inequalities in edentulism by comparing ASPR across countries. Specifically, we sought to identify the highest and lowest performing countries regarding ASPR and to investigate any significant peaks in prevalence during this timeframe. Furthermore, we aimed to analyze the distribution of edentulism and compare absolute differences in ASPR among member states, while examining trends over time from 1990 to 2021 to elucidate inequalities between countries and between sexes.

Materials and methods

The Global Burden of Disease (GBD) 2021 study provides data on 371 diseases and injuries, 88 risk factors, including 204 countries and regions worldwide between 1990 and 2021 for male, female and both sexes [27]. We collected data on ASPR per 100,000 of edentulism from the GBD 2021 database via the Global Health Data Exchange (GHDx) tool (Institute for Health Metrics and Evaluation - http://ghdx.healthdata.org/gbd-results-tool). The GBD 2021 study methodology has been published elsewhere [28]. The case definition of edentulism was considered as the absence of any permanent teeth in the oral cavity. Remission for all age groups was set at zero due to the categorization of this condition as irreversible. Prevalence was assigned as zero during childhood, as edentulism in infancy was not taken into consideration. Estimates started from the age of 15 based on the expectation that permanent teeth would have fully erupted in the majority of individuals. Age-standardized rates (ASRs) were calculated using the GBD-standardized population and a Bayesian meta-regression model (DisMod-MR 2.1t) was employed to ensure consistency in estimates.

We included 28 member states of the EU in this study: Austria, Belgium, Bulgaria, Croatia, Republic of Cyprus, Czechia, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden and United Kingdom (UK). We chose to include the UK in the analysis, since it was an EU member state until 2019.

In order to calculate the ASPR ratio for edentulism for each year between 1990 and 2021, the ASPR of two countries were divided. The highest-ranking rate is the numerator, and the lowest-ranking rate is the denominator. Additionally, inequalities were also calculated between all the countries, by using country-pairs estimations in 2021, in which the higher-ranking country is divided by the lower-ranking one. For the Total Percentage Change (TPC), the GBD study calculates this metric by comparing the prevalence rates of the disease over time, typically expressed as a percentage change per period. The closer the TPC is to zero, the smaller the difference in the ASPR between 1990 and 2021. The TPC can be either negative (indicating a decrease in ASPR) or positive (indicating an increase in ASPR).

The Gini Coefficient (GC) is a statistical measure used to assess relative measure of inequalities, and it is determined by analyzing the distribution of ASPR across member states using the Lorenz curve, which illustrates the cumulative proportion of ASPR relative to the cumulative proportion of the population. Its values range from 0 (perfect equality) to 1 (total inequality). In this study, Stata software and the ineqdeco module were employed for GC calculation, incorporating bootstrap resampling to derive 95% confidence intervals. The Slope Index of Inequality (SII) serves as an absolute measure of inequalities, providing an additional metric for assessing health inequalities by estimating the average absolute difference in the ASPR among countries. It is derived from the beta coefficient (slope) of the linear regression of Pen's Parade, which arranges countries based on their ASPR from lowest to highest, considering the share of the total population for each country. Higher SII values indicate a significant inequality in edentulism between countries with low and high ASPR, while an SII close to zero reflects relatively similar ASPR across countries, indicating minimal inequality in edentulism.

The 95% Uncertainty Interval (95% UI) accounts for variability and potential errors in the modeling process by reflecting a range of plausible values within which the true ASPR is expected to lie. The estimates are derived by sampling 1000 draws from the posterior distribution, and the reported ASPR is the mean value of these draws estimates. It is represented by the 2.5th and 97.5th percentiles of the distribution. The statistical difference was considered if the 95% UI of ASPR of two member states did not overlap.

Results

The EU ASPR for edentulism in 1990 was 4986 (95% UI: 3996 to 6041) and in 2021 it was 4441 (95% UI: 3537 to 5387). In 1990, the ASPR for all countries ranged from 3060 (95% UI: 2336 to 3931) in Sweden to 7962 (95% UI: 6405 to 9568) per 100,000 in Poland. By 2021, the ASPR varied between 3248 (95% UI: 2534 to 3985) in Malta and 7101 (95% UI: 5680 to 8594) per 100,000 also in Poland. The ASPR trend remained relatively steady until 2000 and after 2015. Between 2001 and 2007, there was a significant increase in ASPR in certain countries, including the Netherlands, Poland, Greece, Austria, UK and Ireland. Conversely, Spain, Sweden, and Denmark experienced a decrease during this period. From 2008 to 2013, there was an overall decline in ASPR across most countries, with Denmark, Spain, and Slovakia exhibiting the

lowest peaks. Between 1990 and 2021, the highest ASPR was 8378 (95% UI: 6792 to 10078) found in Poland in 2006 and the lowest one was 1788 (95% UI: 1570 to 1986) found in Spain in 2010 (Table 1; Fig. 1a, and Supplementary Table 1).

The ASPR of edentulism in the male population across the EU exhibited variations over the years, ranging from 4313 (95% UI: 3446 to 5248) in 1990 to 3870 (95% UI: 3074 to 4730) in 2021. The peak occurred in 2004 at 4358 (95% UI: 3771 to 4958), while the lowest point was noted in 2010 at 3010 (95% UI: 2742 to 3305). In 1990, the ASPR for EU-28 member states varied, with Sweden at 3069 (95% UI: 2313 to 3997) and Poland at 7107 (95% UI: 5689 to 8615). The Netherlands reached the highest value at 7778 (95% UI: 6870 to 8766) in 2005, while Spain recorded the lowest ASPR in 2010 at 1748 (95% UI: 1531 to 1958). By 2021, the ASPR ranged from 2714 (95% UI: 2095 to 3368) in Malta to 6317 (95% UI: 5025 to 7640) in Poland. Throughout the entire period, the majority of countries experienced a notable rise in ASPR, followed by a significant decline, ultimately returning to an ASPR similar to that of the initial years. Poland, The Netherlands, Hungary, Ireland, Slovakia, and Slovenia consistently maintained high ASPR throughout the years. Conversely, Sweden, Spain, France, Malta and Denmark consistently exhibited the lowest ASPR throughout the entire period (Fig. 1b and Supplementary Table 1).

In 1990, the ASPR of edentulism in the female population of the EU varied from 3081 (95% UI: 2354 to 3935) in Sweden to 8591 (95% UI: 6950 to 10298) in Poland. Poland consistently held the highest prevalence, peaking at 9272 (95% UI: 7534 to 11087) in 2010. Subsequently, there was a considerable decrease, and Slovenia and Slovakia emerged as the countries with the highest ASPR from 2014 to 2018. In 2019, ASPR ranged from 3741 (95% UI: 2919 to 4604) in Malta to 7726 (95% UI: 6215 to 9292) in Poland, with Spain recording lowest ASPR in EU in 2010 at 1844 (95% UI: 1616 to 2053). Throughout the period, Ireland, Poland, the Netherlands, Slovenia, and Slovakia consistently exhibited high ASPR, while Italy, Malta, France, Spain, Sweden, and Denmark maintained lower ASPR. The ASPR trend of edentulism in the female population showed less homogeneity compared to the male population, with many countries displaying a pattern of steadiness, followed by an increase, subsequent decrease, and ultimately returning to an ASPR similar to the initial years (Fig. 1b and Supplementary Table 1).

The TPC in the EU population exhibited a range of values, with Finland having the lowest at −27.76 (95% UI: −40.74 to −17.23), and Sweden exhibiting the highest TPC at 31.07 (95% UI: −8.84 to 94.22). Other countries with relatively low TPC included Spain and Ireland, with values of −27.51 (95% UI: −40.51 to −17.37) and −17.43 (95% UI: −21.70 to −13.19), respectively (Fig. 2a). The majority of countries fell within the range of −15.1 to 0.0, including Austria, Belgium, Croatia, Bulgaria, Portugal, and Slovenia. Notably, the UK, Greece, and Sweden recorded the highest TPC at 0.93 (95% UI: −5.27 to 10.47), 4.03 (95% UI: −22.23 to 47.19), and 31.07 (95% UI −8.84 to 94.22), respectively. The TPC between males and

Table 1 Age-standardized prevalence rate of edentulism per 100,000 population by EU member state for 1990, 2000, 2010, 2019, 2020, and 2021

Country	1990		2000		2010		2019		2020		2021	
	Prevalence	95% UI	Prevalence	95% UI	Prevalence	95% UI	Prevalence	95% UI	Prevalence	95% UI	Prevalence	95% UI
EU	4986	(3996 to 6041)	4817	(4100 to 5562)	3567	(3241 to 3914)	4353	(3461 to 5277)	4443	(3543 to 5398)	4441	(3537 to 5387)
Austria	5139	(4044 to 6275)	4871	(3823 to 5990)	4025	(3781 to 4290)	4613	(3621 to 5696)	4612	(3608 to 5693)	4619	(3593 to 5695)
Belgium	5195	(4061 to 6330)	4960	(3895 to 6106)	4997	(4731 to 5281)	4743	(3722 to 5838)	4759	(3737 to 5864)	4753	(3703 to 5826)
Bulgaria	5958	(4757 to 7330)	6058	(4839 to 7371)	4604	(4281 to 4892)	5220	(4159 to 6375)	5191	(4121 to 6367)	5187	(4144 to 6367)
Croatia	5900	(4692 to 7159)	5883	(4690 to 7145)	3767	(3455 to 4106)	5156	(4065 to 6370)	5146	(4138 to 6268)	5151	(4083 to 6285)
Cyprus	4570	(3541 to 5616)	4370	(3434 to 5348)	4190	(3283 to 5160)	4197	(3259 to 5228)	4196	(3275 to 5170)	4205	(3280 to 5211)
Czechia	6385	(5127 to 7728)	5572	(4869 to 6327)	4963	(4643 to 5260)	5585	(4487 to 6816)	5564	(4444 to 6765)	5551	(4400 to 6746)
Denmark	4217	(3290 to 5168)	4037	(3145 to 4990)	2485	(2273 to 2732)	3830	(2989 to 4779)	3830	(2993 to 4756)	3843	(2969 to 4728)
Estonia	5124	(4124 to 6179)	5278	(4261 to 6354)	3875	(3569 to 4172)	4564	(3650 to 5500)	4559	(3673 to 5486)	4552	(3655 to 5545)
Finland	6229	(5100 to 7383)	5708	(5513 to 5890)	3079	(2853 to 3333)	4475	(3486 to 5543)	4493	(3497 to 5504)	4491	(3495 to 5577)
France	3991	(3094 to 4965)	3827	(2951 to 4739)	2550	(2342 to 2784)	3650	(2827 to 4493)	3650	(2846 to 4491)	3662	(2885 to 4554)
Germany	4393	(3418 to 5400)	4546	(4353 to 4732)	2551	(2433 to 2675)	3943	(3076 to 4839)	3942	(3058 to 4843)	3947	(3065 to 4857)
Greece	4915	(3851 to 6039)	5299	(4216 to 6552)	4008	(3568 to 4493)	4994	(4032 to 6164)	5003	(3983 to 6150)	5014	(4023 to 6176)
Hungary	6647	(5300 to 8098)	5583	(4701 to 6725)	5637	(5300 to 5938)	5757	(4630 to 6997)	5736	(4555 to 6952)	5716	(4563 to 6911)
Ireland	6130	(4938 to 7432)	5474	(5006 to 5935)	5513	(5226 to 5769)	5046	(3978 to 6206)	5036	(3959 to 6179)	5015	(3889 to 6240)
Italy	4048	(3174 to 4976)	3971	(3115 to 4881)	2945	(2287 to 3625)	3929	(3082 to 4844)	3933	(3086 to 4838)	3931	(3077 to 4846)
Latvia	4428	(3558 to 5406)	4721	(3806 to 5767)	2975	(2684 to 3301)	4047	(3237 to 4934)	4045	(3240 to 4946)	4042	(3239 to 4884)
Lithuania	4243	(3372 to 5114)	4498	(3612 to 5439)	3016	(2810 to 3222)	3839	(3058 to 4694)	3834	(3040 to 4734)	3824	(3060 to 4684)
Luxembourg	4613	(3611 to 5725)	4314	(3362 to 5380)	3779	(3476 to 4084)	4109	(3211 to 5081)	4101	(3196 to 5053)	4106	(3209 to 5060)
Malta	3760	(2908 to 4622)	3532	(2749 to 4395)	3508	(3224 to 3814)	3265	(2514 to 4013)	3258	(2522 to 3999)	3248	(2534 to 3985)
Netherlands	6307	(5042 to 7630)	6061	(4812 to 7381)	4709	(4436 to 4990)	5781	(4544 to 7073)	5781	(4614 to 7066)	5793	(4564 to 7122)
Poland	7962	(6405 to 9568)	7517	(6031 to 9050)	8300	(6733 to 9967)	6005	(4834 to 7253)	7131	(5692 to 8635)	7101	(5680 to 8594)
Portugal	4634	(3646 to 5724)	4360	(3391 to 5314)	4305	(4063 to 4536)	4203	(3276 to 5225)	4189	(3263 to 5170)	4186	(3284 to 5166)
Romania	5901	(4675 to 7163)	5888	(4658 to 7147)	4228	(3914 to 4509)	4992	(3959 to 6138)	4981	(3921 to 6100)	4950	(3940 to 6056)
Slovakia	7017	(5617 to 8470)	6934	(5637 to 8426)	6221	(5880 to 6558)	6012	(4752 to 7309)	6011	(4775 to 7273)	5998	(4772 to 7263)
Slovenia	6663	(5374 to 8144)	6507	(5237 to 7885)	4906	(4571 to 5219)	5736	(4568 to 6972)	5720	(4559 to 6930)	5721	(4572 to 6969)
Spain	4829	(3891 to 5686)	4258	(3779 to 4709)	1788	(1570 to 1986)	3446	(2674 to 4247)	3459	(2683 to 4305)	3464	(2706 to 4316)
Sweden	3060	(2336 to 3931)	3261	(2525 to 4062)	2880	(2294 to 3661)	3995	(2985 to 5329)	4007	(2965 to 5359)	3988	(2987 to 5282)
UK	4406	(3460 to 5401)	5634	(4569 to 6770)	3078	(2537 to 3692)	4328	(3533 to 5181)	4352	(3578 to 5203)	4387	(3637 to 5221)

Fig. 1 **a**. Age-standardized prevalence rates of edentulism by EU member states for both sexes between 1990 and 2021 (Blue line: European Union; Orange line: Member state). **b.** Age-standardized prevalence rates of edentulism by EU Member States for males and females between 1990 and 2021 (Purple: female; Green: male; Solid line: European Union; Dashed line: Member state)

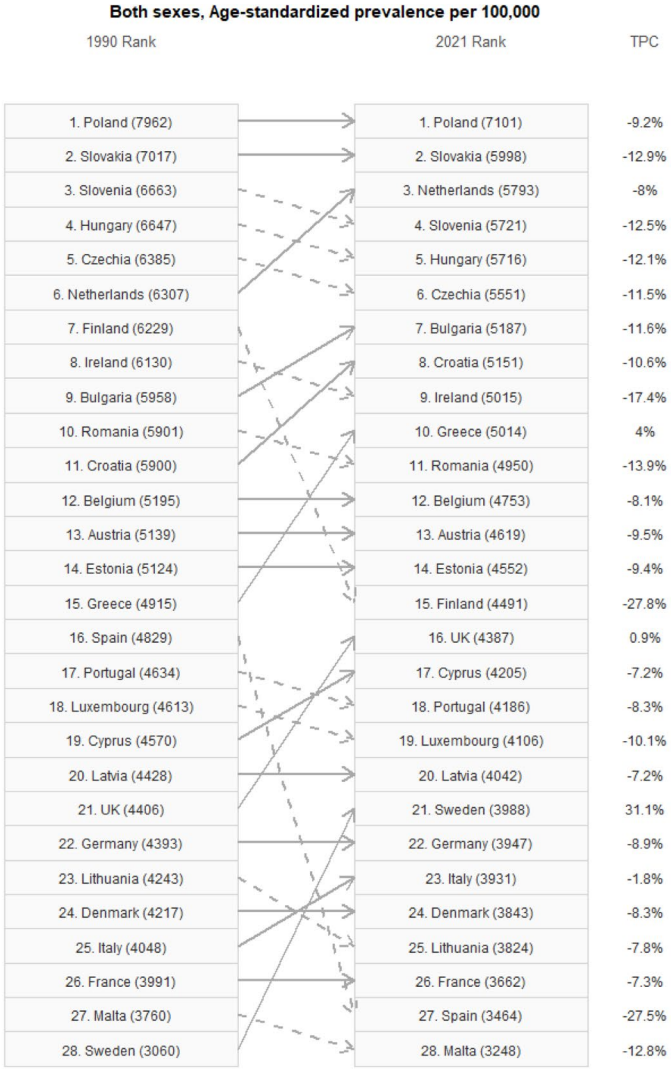
females exhibited a significant similarity in terms of the ranking of countries. However, the TPC for males was slightly higher at −8.41 (95% UI: −10.38 to −6.04) for the EU, ranging between − 28.92 (95% UI: −41.92 to −18.15) in Finland and 14.86 (95% UI: −21.28 to 75.18) in Sweden. In contrast, for females, the EU TPC was − 9.28 (95% UI: −11.52 to −7.07), with a range between − 29.81 (95% UI: −43.55 to −17.97) in Spain and 45.26 (95% UI: 1.22 to 114.82) in Sweden (Fig. 2b and Supplementary Table 2).

The ASPR ratio for males across all EU member states for 2021 exhibited a range from 1.00 (as observed in Germany and Italy, Austria and Lithuania, Romania and Greece) to 2.33 between Poland and Malta. Several pairs of countries did not present overlapping 95% UI, most of them were above a ratio of 1.59, such as Slovakia and Spain at 1.78, Malta and the Netherlands at 1.93, and France and Hungary at 1.68. For the female population, the ASPR ratio for pairs of countries showed a more constrained range, varying between 1.00 (as seen in Estonia and Cyprus, Belgium and Austria, and Italy and Germany) and 2.07 between Poland and Malta. A number of ratios for pairs of countries exhibited statistical differences, most of them above 1.53 of ratio, including Czechia and Lithuania at 1.58, Hungary and Malta at 1.65, and Poland and Spain at 2.04 (Supplementary Fig. 1).

The ASPR ratios for the highest and lowest-ranking countries for both sexes exhibited a hectic trend, ranging between 1.84 as the lowest ratio in 2018/2019 and 4.64 as the highest in 2010. There were notable peaks from 1990 to 2021: 3.10 in 2005, 4.64 in 2010, and 2.19 in 2020/2021. The ASPR ratio for females held the highest position until 2003 and between 2008 and 2013, in which the ASPR ratio for male surpassed it. Additionally, the ASPR ratio for females reached the highest ratio, above males and both sexes, in 2010 at 5.03. Starting in 2007, all ASPR ratios experienced a significant increase, with the ASPR ratios for females, males, and both sexes reaching 5.03, 4.04, and 4.64 at 2010, respectively. Between 2014 and 2019, the trend reverted to a pattern similar to the initial one, with ratios ranging from 1.72 to 2.04. However, after 2019 there was a sudden increase in the trend for female, male, and both sexes. None of the ASPR ratios between 1990 and 2019 presented overlapping 95% UI (Fig. 3 and Supplementary Table 3).

The GC for both sexes was 0.121 (95% UI: 0.095 to 0.147) in 1990 and decreased to 0.104 (95% UI: 0.079 to 0.129) by 2021. Throughout the entire period, the male

a



b

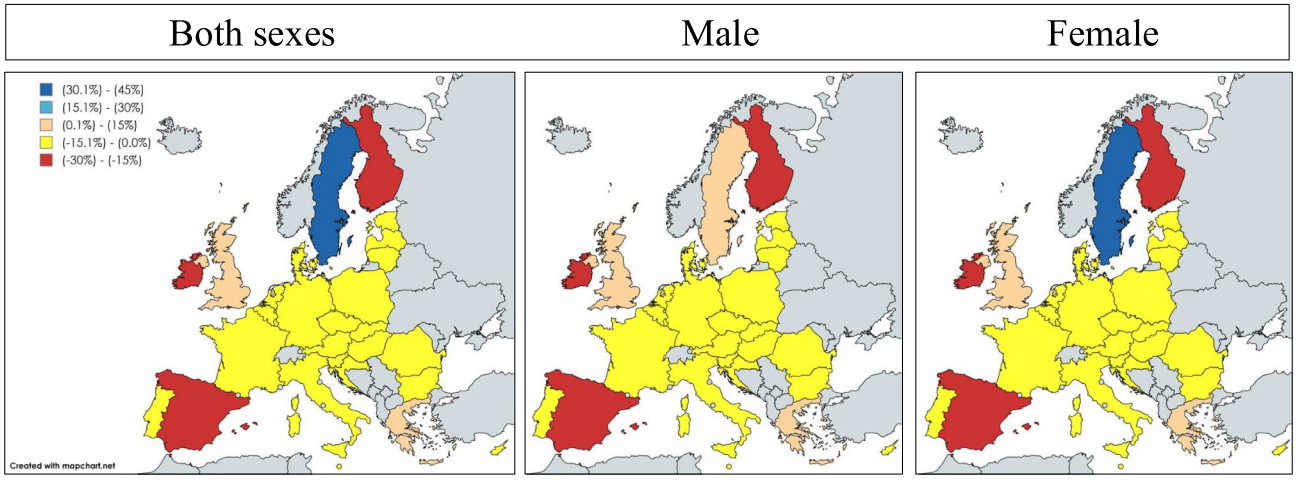


Fig. 2 **a**. Total percentage change of age-standardized prevalence rate for edentulism for 1990–2021. Legend: TPC: Total Percentage Change; values in parentheses are age-standardized prevalence rates (ASPR). **b.** Total percentage change of age-standardized prevalence rate for edentulism for 1990–2021

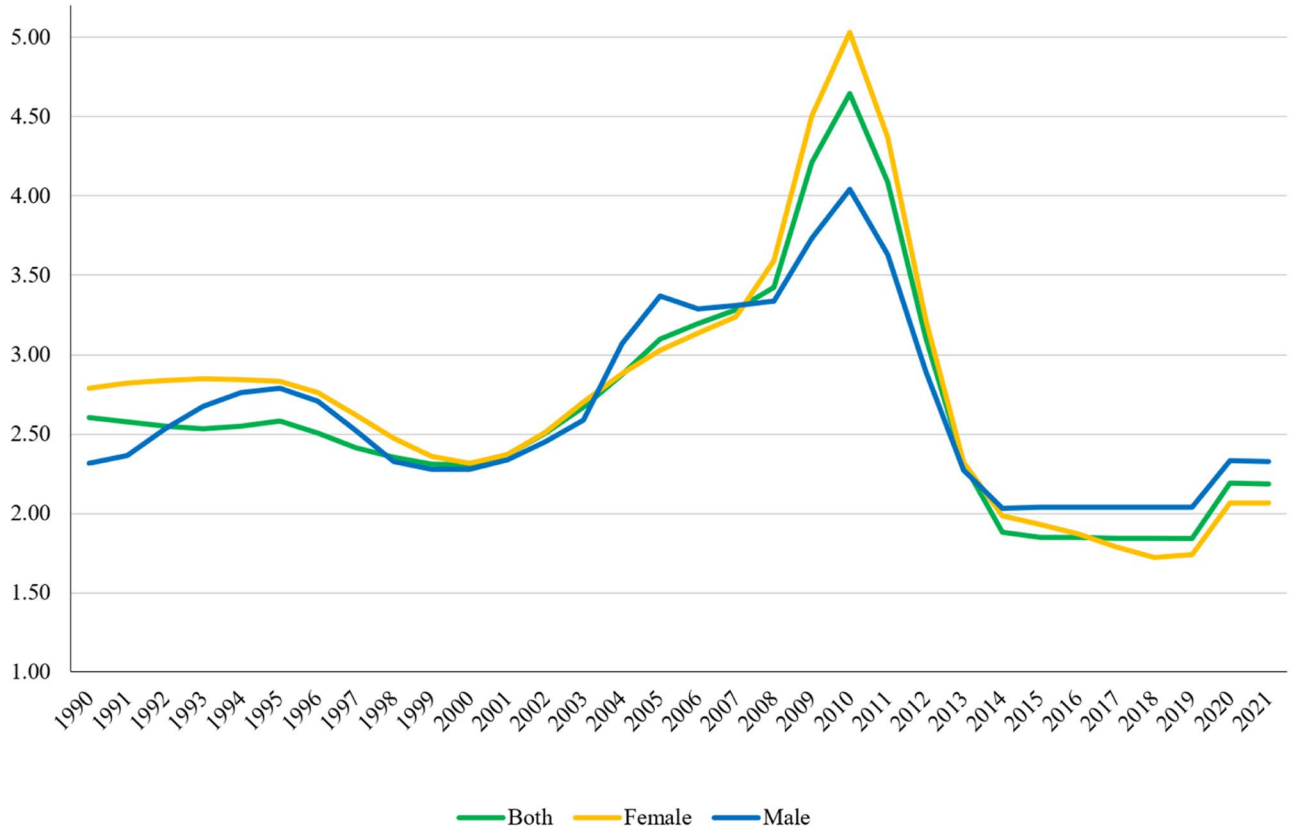


Fig. 3 Ratio of age-standardized prevalence rate of edentulism in EU Member States between 1990 and 2021

population consistently exhibited higher GCs compared to the female population. The GC showed a slight increase in 1995, reaching 0.130 (95% UI: 0.099 to 0.161) for both sexes. Subsequently, there was a decline, reaching 0.112 (95% UI: 0.086 to 0.138) in 2000. The highest GCs were observed in 2010, reaching 0.178 (95% UI: 0.129 to 0.228) for both sexes, 0.179 (95% UI: 0.131 to 0.228) for females and 0.180 (95% UI: 0.136 to 0.225) for males, marking the highest values in this analysis. An abrupt decrease in the trends is apparent between 2010 and 2014. Between 2015 and 2019, the trend exhibited lower and more steady values in the analysis, ranging from 0.107 (95% UI: 0.087 to 0.128) for females in 2015 to 0.105 (95% UI: 0.086 to 0.124) for males in 2019. There is a sudden increase in the trends in 2020 and a slight decrease in 2021 (Fig. 4 and Supplementary Table 4).

The SII ranged from 0.075 (95% UI: 0.060 to 0.090) in 1990 to 0.059 (95% UI: 0.046 to 0.071) in 2021, for both sexes. The highest SII was in 2009 (0.102, 95% UI: 0.075 to 0.128) and the lowest was observed in 2016 (0.052, 95% UI: 0.044 to 0.059). The female population presented higher SII, with peaks in 1995 (0.091, 95% UI: 0.075 to 0.106), 2005 (0.090, 95% UI: 0.071 to 0.110), and 2010 (0.112, 95% UI: 0.086 to 0.138). The SII for males in the same years were respectively 0.077 (95% UI: 0.062 to 0.091), 0.081 (95% UI: 0.065 to 0.096), and 0.104 (95% UI: 0.079 to 0.129). A sudden decrease in the trend was found between 2000 and 2015. The SII reached the lower values between 2015 and 2019, ranging from 0.052 (95% UI: 0.045 to 0.060) and 0.054 (95% UI: 0.044 to 0.063) for both sexes. Similarly to GC, the trend also showed an increase in 2020, reaching 0.059 (95% UI: 0.046 to 0.072) for both sexes (Fig. 4 and Supplementary Table 4).

Discussion

Our analysis of the trends in ASPR edentulism in the EU reveals important levels of inequalities in edentulism across space and time. The similarity in prevalence rates of 1990 and 2021 is marked by relatively low levels of inequality. However, the fluctuations in ASPR around 2005, followed by a decrease in 2010 and an increase from 2010 to 2015, indicate inconsistencies in edentulism trends. Inequalities in prevalence peaked in 2005 and further escalated in 2010, with the highest rate country exhibiting a prevalence 5.03 times higher than the lowest rate country for the female population and 4.64 times for both sexes. However, there is a reduction in these inequalities by 2019, with the highest rate country having a prevalence only 1.84 times higher than the lowest rate country for both sexes.

Malta and Poland were the top two countries showing the highest ASPR ratios for female and male population

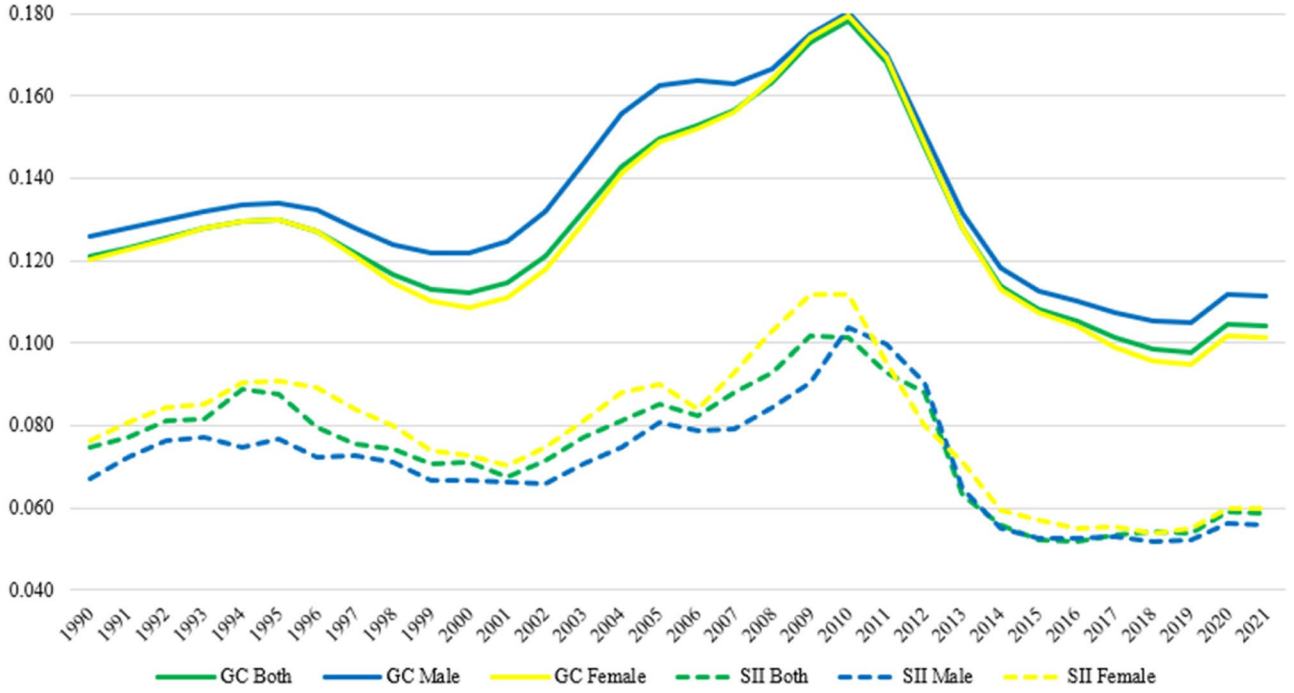


Fig. 4 Gini Coefficient and Slope Index of Inequality of age-standardized prevalence rate of edentulism in EU Member States between 1990 and 2021. Legend: SII: Slope Index of Inequality; GC: Gini Coefficient

in 2021. This is due to the fact that Malta had a remarkably low ASPR of edentulism; conversely, Poland had the highest ASPR for edentulism. Furthermore, our results show that Poland has one of the highest rates of edentulism among all countries, peaking in 2006 before gradually declining until 2015 and another sudden increase in 2020. The consistently higher ASPR of edentulism among females, particularly in Slovenia, Portugal, Poland, and Austria, may reflect a combination of demographic and socioeconomic factors [1]. In Slovenia and Austria, women's longer life expectancy and limited public dental coverage are potential influences [29–31]. In Portugal, older women had poor access to dental care before early 2000 s reforms, especially in rural areas [32, 33]. In Poland, post-communist healthcare changes and high out-of-pocket costs may have disproportionately affected low-income women with limited health literacy [34, 35].

Our study showed that the ASPR inequalities between countries was mostly higher in the male population in comparison to the female population in 2021. The ratio of ASPR for edentulism in 2021 reached 2.33 for the male population (Malta and Poland), while for the female population, it reached 1.87 (Malta and Poland). A similar trend was found for DALY rates of NCDs in European Economic Area (EEA), where the highest ratio for female population was 1.50, while the highest ratio for male was 1.90 [23]. The same association was found between 1990 and 2019 for NCDs, since the rates for males presented extensive differences between the highest and the lowest rates [23]. Gender inequalities play a significant role in both overall NCDs [23, 36] and edentulism [14]. Research suggests that men are generally more prone to engaging in riskier behaviors such as smoking, excessive alcohol consumption, and drug use [37], which increase the likelihood of developing NCDs [38] and exacerbate oral health problems leading to edentulism. Additionally, men are increasingly less likely to utilize regular check-ups and preventive healthcare visits [37].

Other NCDs and edentulism share several common risk factors, primarily revolving around lifestyle choices and underlying health conditions: poor diet, tobacco use, excessive alcohol consumption, and medical adherence [39–41]. Moreover, systemic conditions like diabetes compromise oral health by weakening the body's ability to fight infection, leading to periodontal disease, dental caries, and eventual tooth loss [42, 43]. Cardiovascular disease is closely linked to oral health, as poor oral hygiene may increase the risk of heart conditions, while systemic health issues from cardiovascular diseases can also negatively impact oral health, creating a bidirectional relationship between the two [44]. A study found a high prevalence of 97.5% in individuals over 65 years with less than 28 natural teeth. The outcome of the study suggests a negative correlation between tooth retention and socioeconomic status indicators, while a positive correlation was observed with employment status in Irish adults in 2002 [45]. In Ireland, associations between tooth retention and factors such as exposure to fluoridated water

supplies, regular dental checkups, and consistent brushing habits have also been found [45].

Previous research has shown that there are significant disparities in adult dental health care financing and statutory coverage throughout European countries [46]. A study including 11 European countries show that even though public sources typically pay for one-third of dental care costs, out-of-pocket paying is still very prevalent [47]. This frequently results in untreated dental issues and uneven access, especially for low-income groups [48]. Dental care in many European countries is generally focused on treatment despite early prevention initiatives, underscoring the need for evidence to guide policy-making and strengthen preventative measures [49].

Relatively low levels of inequality in edentulism ASPR were found between 1990 and 2000, and also between 2013 and 2021. In the past decades, dental healthcare management in the EU went through many changes and differed significantly among member states due to differences in healthcare systems and policies [50, 51]. Each EU member state has its own healthcare system, which has resulted in different approaches to dental healthcare. For instance, countries such as the UK and Sweden have publicly funded healthcare systems that cover dental services to varying degrees. Other countries rely more heavily on private insurance or out-of-pocket payments [52]. Additionally, a study revealed that countries without public dental care coverage had higher inequalities in the use of dental care services than countries with some degree of public coverage [46]. Even in countries with full universal healthcare systems covering dental care, evidence has shown that persistent inequalities remain in access to dental care [53, 54].

Results of a number of studies show that the prevalence of edentulism was not linked to a country's economic situation or the number of dentists per capita. Edentulism was uncommon among people of working age, according to studies conducted in various European countries [55]. There has been a documented reduction in edentulism, but significant differences remain between countries and within countries' geographical regions, as well as among groups with varying backgrounds [55, 56].

According to a cross-sectional study with data from 2006, there were significant inequalities in the use of dental services among people above 50 years of age in Europe, depending on their socioeconomic position. This implies that even if achieving universal coverage is a crucial first step toward ensuring equal access, some groups may still be unable to fully benefit from these services due to other obstacles like income, education, or geographic location [57, 58]. Edentulism already has high levels of inequalities, and it is indicated that inequalities persist in denture-wearing rates among different socioeconomic levels [30, 59]. In 2006/7, denture-wearing was found to be disproportionately concentrated among the poor elderly populations in Denmark and Sweden, aligning with the highest levels of inequality. In contrast, Poland was the only country where denture use was more prevalent among individuals at the upper end of the income scale compared to those at the lower end [30].

In 2007, financial barriers led to high non-use of dental care in Estonia, Greece, Latvia, and Iceland; while Czechia, Luxembourg, the UK, and the Netherlands had higher use linked to financial accessibility. The study also found that higher education levels correlated with greater dental care use in Europe [60]. Some analysis show that individuals from Poland belonging to the highest income group exhibited a nearly twofold higher likelihood of accessing dental services compared to those in the lowest income [35, 61]. Education level and place of residence also showed that higher education and urban residencies had higher rates of dental care utilization compared to their counterparts [35, 61]. Countries like Denmark, Norway, Iceland, and Poland show increased rates of people not accessing dental care when their direct contribution to dental expenses exceeds 50% of the total cost [60]. The differences are evident even in countries that tend to have comparable social and economic circumstances, such the Nordic countries, where the rates of edentulism among 75-year-old participants in the cities of Sweden, Denmark, and Finland were 27%, 45%, and 58%, respectively, in the early 1990 s [62]. Several studies report that there was no consistent reduction in inequalities of non-utilization of dental care in Scandinavian nations, even with all the egalitarian political and social systems [60, 63]. However, public funding for oral health varies significantly across countries, with Norway and Sweden covering most major healthcare expenses but offering limited coverage for dental care, which remains expensive in the Nordic region [64].

The TPC in edentulism according to the ASPR was considered low, primarily because the countries exhibited similar ASPR values in both 1990 and 2021, despite significant fluctuations in-between. Except from Sweden, Greece, and the UK, all the other countries slightly decreased the ASPR for edentulism. For this reason, most TPC were presented as negative values. Our results suggest that most countries in the EU have improved their dental healthcare systems, contributing to a decrease in the ASPR of edentulism over the past three decades. However, the increase in ASPR observed in Sweden, the UK, and Greece may indicate a deterioration in oral healthcare or inconsistencies in data collection methods. Potential reasons for the worsening ASPR in these countries since 1990 could include reduced access to affordable dental care, shifts in public health policies, economic constraints affecting dental services, or demographic changes leading to higher-risk populations.

Sweden, Denmark, Spain, and Malta consistently showed the lowest ASPR rates over the study period. In Sweden, where dental care is free for those under 24, mean tooth loss ranged from 0.4 to 1.8 between 1972 and 2002 [65] and edentulism dropped from 16% in 1973 to 0.3% by 2013, mainly due to reductions in caries and periodontitis [66]. Denmark's low rates may be linked to major reforms, starting with the 1986 Act on Dental Care, which expanded services and integrated dental care into primary healthcare by 2005, reducing oral diseases [67–69]. Spain maintained low ASPR rates, supported by a comprehensive national oral health plan, universal healthcare coverage, and a strong focus on preventive care [46, 70–72]. Although the 2008 economic crisis impacted vulnerable groups, Spain's strong healthcare system helped sustain low rates of edentulism [73]. In contrast, Poland had the highest ASPR through 2013 and again in 2020–2021. After its 1990s market transition, it introduced reforms to modernize healthcare, improve access, and promote preventive and oral care [74, 75], including subsidized dental services for children and low-income families and incentives for dentists in underserved areas [34]. Despite this, Poland remained highest in ASPR of edentulism, reflecting persistent challenges in reducing tooth loss and improving oral health [70, 76].

Given the paucity of epidemiological research on edentulism and tooth loss in numerous European countries [55], this study represents a significant contribution to the existing literature. It is the first study to comprehensively report trends in the prevalence rate of edentulism and the related health inequalities within all EU member states. The paper employs several methodological strengths. The inclusion of a 31-year follow-up period, ranging from 1990 to 2021, adds a longitudinal dimension, providing a thorough examination of how edentulism and its inequalities have evolved over time. One of the strengths of our paper is the utilization of very recent data and estimates from the GBD 2021, ensuring that our findings are based on the most current and reliable information available. The decision to use age-standardized rates enhances the study's reliability, offering a more harmonized and validated measure for cross-country and temporal comparisons. Another noteworthy strength lies in the methodology's incorporation of three inequality measures: the GC, SII, and ASPR ratios. This multifaceted approach enables a nuanced interpretation of how inequalities manifest throughout the years. Furthermore, the inclusion of sex-specific analysis adds depth to the findings, by focusing on the differential impact of edentulism and its inequalities across sexes, and both sexes together.

It is, however, of the utmost importance to acknowledge and address the limitations of the present study. The GBD estimates include issues related to the availability of primary data, variations in case definitions, non-standardized measurement methods, collinearity problems, and inconsistencies in prevalence rates [1]. As we utilized data from the GBD study, some of their limitations are inherently present in our analysis, as detailed in the source publication [77]. The GBD data, estimated using mathematical models and data from neighboring countries, may exhibit deviations and biases due to varying data quality and economic conditions across countries, leading to potential heterogeneity in edentulism estimates. The observed fluctuations in edentulism prevalence may reflect methodological artifacts related to variations in data availability, modeling assumptions, or estimation procedures used by the GBD study, rather than true changes in population-level morbidity. Furthermore, the approach of employing an overlapping 95% UI to assess statistical significance has its strengths and weaknesses. While effective in confirming significance when two countries do not overlap, it may lead to potential bias when there is slight overlap, possibly resulting in falsely claiming absence of significance. Thus, it is crucial to recognize the limitations of relying solely on UIs for determining statistical significance. Even with this limitation, using the 95% UI is still more favorable than the 95% CI because it incorporates model uncertainty, making it a more significant measure. Another limitation is related to the ratio of ASPR being assessed using only the highest and the lowest-country for each year. To enhance the robustness of our findings, we performed cross-comparisons among all countries in 2021 and incorporated GC and SII to provide more accurate measures of inequality. It is important to note, however, that our study did not delve into subnational inequality analysis, a critical aspect given the presence of intra-country inequalities. However, these estimates are not currently estimated by the GBD for the EU. Future studies should prioritize subnational analyses to gain a more nuanced understanding of healthcare needs within specific regions of a country.

Conclusions

Our analysis of the age-standardized prevalence rates of edentulism in the European Union reveals significant levels of inequalities between member states over the past three decades. The prevalence rates between 1990 and 2021 show a remarkable degree of stability between countries, but we identified important peaks during this period. However, the prevalence fluctuations around the years 2000 and 2007, followed by a subsequent overall decrease between 2007 and 2013, highlight a dynamic nature in the trends of edentulism prevalence. The inequalities in edentulism prevalence reached a peak in 2005, escalating even further in 2010, with the highest rate country exhibiting a prevalence 5 times higher than the lowest rate country. The male population showed a

higher level of inequality when compared to the female population. This high level of inequality underscores the need for targeted interventions and policy measures to address oral health inequalities across European nations. It is encouraging, however, to observe a reduction in these inequalities by 2021, with the highest rate country having a prevalence only 2.33 times higher than the lowest rate country. These findings prompt reflection on the potential impact of various factors, including socio-economic factors, healthcare policies, and public awareness initiatives, on the prevalence of edentulism. It is crucial for policymakers and public health officials to consider employing evidence-based strategies to further narrow the existing gaps in oral health outcomes.

Abbreviations

ASPR	Age-standardized prevalence rate
ASRs	Age-standardized rate
EEA	European Economic Area
EHIS	European health interview survey
EU	European Union
EU-SILC	EU statistics on income and living conditions
GBD	Global Burden of Disease
GC	Gini Coefficient
GHDx	Global Health Data Exchange
NCDs	Non-communicable diseases
SII	Slope Index of Inequality
TPC	Total Percentage Change
UI	Uncertainty Interval
UK	United Kingdom

Supplementary Information

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Supplementary Material 1: Supplementary Table 1:Age-standardized prevalence rate, 95% UI, from 1990 to 2021 for 28 member states of the European Union. Supplementary Table 2: Total percentage change of age-standardized prevalence rate for edentulism for both sexes, male, and female for 1990 to 2021. Supplementary Table 3: Ratio of age-standardized prevalence rate of edentulism in EU Member States between 1990 and 2021. Supplementary Table 4: Gini Coefficient and Slope Index of Inequality of age-standardized prevalence rate of edentulism in EU Member States between 1990 and 2021.

Supplementary Material 2: Supplementary Figure 1: Ratio of age-standardized prevalence rate for edentulism between EU Member States by sex in 2021. White represents ratios closer to 1 (equality), and red color represents ratios further from 1 (inequality). Ratios for females are above the diagonal line, and for males are under the line. Ratios in bold and underlined represent prevalence rate of compared countries 95% UI do not overlap.

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Authors' contributions

CASA and OV conceptualized the study. CASA, NM, EL, CMB, TAE, JS, and OV assisted in developing the methodology. CASA, NM, and CMB conducted statistical analysis. CASA and OV prepared and wrote the original draft. CASA, NM, EL, CMB, TAE, JS, and OV contributed to the research visualization, reviewed, and edited the manuscript. EL, TAE, and OV supervised the research.

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Data availability

Data are available in a public, open-access repository (ghdx.healthdata.org). Additional data supporting the findings of this study can be obtained from the corresponding author upon reasonable request.

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

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