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Global disparities in the burden of pancreatic cancer (1990–2021): insights from the 2021 Global Burden of Disease study

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Abstract

Background Pancreatic cancer (PC) is a highly lethal malignancy, ranking seventh among cancer-related deaths worldwide. This study utilizes data from the 2021 Global Burden of Disease (GBD) study to examine the global burden of PC and associated health inequalities from 1990 to 2021, with a focus on key risk factors such as obesity, high fasting plasma glucose, and the Socio-Demographic Index (SDI).

Methods Disability-Adjusted Life Years (DALYs) for PC were estimated using GBD 2021 data. The analysis incorporated SDI, age, gender, and major risk factors, including obesity and high fasting plasma glucose. Descriptive statistics and visualizations, such as age-sex pyramids and geographic maps, were employed to assess global, regional, and national burdens. Health disparities were quantified using the Concentration Index (CI) and the Slope Index of Inequality (SII), with CI assessing relative health distribution by income and SII measuring absolute socioeconomic inequality.

Results Globally, PC-related DALYs rose from 1.76 million in 1990 to 4.25 million in 2021 (141.48% increase), with the age-standardized DALY rate up 11.57% to 48.71 (95% UI 23.43 to 74.33). The burden was highest in high SDI regions, while low SDI areas still faced elevated rates; transitional and developing economies showed the highest age-standardized DALY rates. The SII increased from 189.63 (95% CI 177.65 to 245.17) in 1990 to 321.17 (95% CI 294.48 to 379.722) in 2021, indicating widening socioeconomic disparities.

Conclusion PC remains a significant global health challenge with growing socioeconomic and geographic disparities. Urgent action is needed to address modifiable risk factors (e.g., obesity, diabetes) through enhanced healthcare infrastructure, early detection, and treatment access in low SDI countries, alongside improved data systems and international collaboration.

Keywords Pancreatic cancer, 2021 Global burden of disease, Health inequality, DALYs, Socio-demographic index

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Introduction

Pancreatic cancer (PC) is a highly aggressive malignancy that originates from abnormal cell growth in the pancreas, leading to significant disruptions in its structure and function [1]. It has a strong association with risk factors such as smoking, being overweight (modifiable factors), and having diabetes or a family history (non-modifiable factors). Symptoms can be mild and unclear, making the disease challenging to diagnose in its early stages. For example, belly pain, unexplained weight loss, and yellowing of skin or eyes may be experienced by some people [2]. As the disease progresses, it may obstruct the intestines and spread to other organs [3, 4]. PC progresses rapidly, resulting in an unfavorable prognosis and ranking it as the 7th leading cause of cancer mortality worldwide, following lung, colorectal, stomach, and liver cancer [5, 6].

PC serves as an ideal case study for examining global health inequalities due to its rising incidence and uneven geographic distribution. Socioeconomic factors, like access to healthcare and lifestyle risks, are also strongly associated with PC. The global burden of PC has increased over the past 30 years, especially in high-income countries. The age-standardized DALY rate for PC increases substantially from 1990 to 2019 by 16.3% among low SDI countries and 52.5% among low-middle SDI countries, compared to a much smaller increase of 5.3% in high SDI countries [7]. In low- and middle-income countries (LMICs), the disease burden remains unevenly distributed. Recent epidemiologic data reported by Xiao Li et al. indicate that low SDI countries bear a disproportionately high burden of PC compared to what would be expected. This is largely attributed to systemic issues in early detection and limited access to advanced treatment modalities [8]. Therefore, a better understanding of these trends is urgently needed.

This research is based on the 2021 GBD study, which provides comprehensive data for analysis. It offers valuable epidemiological insights into the global burden of PC by leveraging this robust dataset. It aims to analyze global trends in PC and its socio-economic correlations from 1990 to 2021. The study focuses on LMICs and high-risk groups. It fills a gap in current research about regional differences and the effect of socio-economic factors on PC.

The study effectively highlights socioeconomic disparities in PC burden and integrates advanced statistical methods, such as the Socio-Demographic Index (SDI), Disability-Adjusted Life Years (DALY) estimations, and inequality metrics like the Slope Index of Inequality (SII) and Concentration Index (CI), alongside cross-temporal and cross-regional analyses. This index helps understand the link between socio-economic development and PC outcomes. This study is a cross-temporal and cross-regional analysis. It shows how the PC burden has changed and how socio-economic factors have influenced this trend. Furthermore, it provides new insights into the disproportionate distribution of the PC burden, particularly in underrepresented regions. The paper points out the regions that necessitate targeted public health interventions. Together, these elements make it a methodologically comprehensive and relevant contribution to understanding and addressing global PC challenges.

This research highlights the steadily increasing strain on healthcare systems and resources, especially in LMICs, as the global burden of PC continues to rise. The increasing prevalence of PC demands significant investment in healthcare infrastructure, early detection programs, and specialized treatments to meet the needs of affected populations. The increasing burden underscores the urgency of prioritizing PC in health policy agendas to ensure that healthcare systems are adequately prepared to address the growing demand for care and mitigate associated socioeconomic disparities.

The research addresses two key questions: (1) How has the PC health profile evolved in relation to SDI from 1990 to 2021? (2) What trends in PC-related health disparities have emerged over this period? Therefore, the findings of this study are intended to inform healthcare planners and policymakers in designing effective healthcare strategies and allocating resources to mitigate PC-related health disparities and manage its future global burden.

Methods

Data sources

In this study, we utilized data from the 2021 GBD study on DALYs for PC at the international, continental, and country levels. We used SDI, a composite measure of income per capita, educational attainment, and fertility rates, to assess the influence of socio-economic factors on the burden of PC. SDI was selected because it effectively integrates economic, educational, and demographic dimensions, offering a robust proxy for healthcare access and disease risk, unlike single-indicator measures such as income alone. The multidimensional approach taken here is especially relevant to PC, as its burden is greatly influenced by social and economic factors. Furthermore, SDI's standardized methodology ensures that all comparisons could be made across countries and across times [9].

SDI values range from 0 to 1. A value of 0 means low income, low education, and high fertility. Thus, a value of 1 means high income, high education, and low fertility. Countries were divided into five SDI groups: low, low-middle, middle, high-middle, and high. These quintiles were consistently applied across all years (1990–2021) using predefined SDI cut-offs from the GBD dataset to ensure comparability over the study period, though alternative cut-offs were not tested for robustness [9].

Countries like Niger and Somalia were in the low SDI group. They faced significant socio-economic challenges. In contrast, countries such as Norway and Switzerland were in the high SDI group. These countries had well-developed socio-economic systems [9]. The use of SDI cut-offs makes it possible for this categorization to support meaningful and reliable comparisons of health outcomes and disparities across the range of socio-economic contexts. Information on PC cases was obtained from the ICD-10 codes, C25.0-C25.9 [10].

We acknowledge some limitations of this GBD dataset, especially for low SDI regions. Data quality and availability in these areas may be compromised by underreporting, incomplete vital registration systems, and limited diagnostic infrastructure, potentially introducing biases in disease burden estimates. To overcome these limitations, the GBD study uses advanced methods of modeling such as Bayesian meta-regression and cross-validation to estimate disease burden in the absence of adequate data. However, such estimates may be of greater uncertainty than for regions with higher SDI where data sources are better and more reliable. Despite this, the GBD dataset is the most comprehensive and standardized, as well as the one that systematically adjusts for data gaps and biases across regions.

Mortality and DALY analysis by age and sex were further conducted across 204 countries and territories. The primary measure of disease burden is DALYs, which combine years of life lost due to early death (YLL) and years lived with disability (YLD). As a measure, DALYs enable obtaining a broad global overview of the fatal and nonfatal outcomes of PC [11]. DALYs are different from the incidence or mortality rate in that they can consider differences in age structures and health outcomes for cross-population comparisons on a global level and hence for assessing global health inequalities. Age-standardized DALY rates are calculated to account for differences in age distributions across populations, enabling fair comparisons between countries and regions. This process involves applying a standard population age structure (based on the GBD reference population) to the observed age-specific DALY rates in each country. By weighting these rates according to the standard population, we derived age-standardized rates that reflect the burden of pancreatic cancer independent of demographic variations [12]. Regarding gender-related biological differences, stratified analysis was conducted by sex to assess any significant differences in disease burden between males and females.

For trends, therefore, we have plotted linear time series scatter plots to describe the gender-differentiated global burden of PC from 1990 to 2021. PC trends were visualized through age-sex pyramids, illustrating changes in the distribution of PC patients across age classes over time. Stacked bar charts provided a detailed visualization of the burden's distribution. Furthermore, we analyzed the burden of PC and employed data visualization to present national DALYs. We also divided the DALYs by the populations of the countries in question and age-standardized DALY rates per 100,000 people in each country. This approach clarified the global burden of PC and its disparities.

Measurement of health inequalities

Total DALYs and country-level age-standardized DALY rates were estimated to assess the health inequality of PC. To measure income-related health inequalities, we used two well-known measures that are recommended by the World Health Organization: the SII and the CI. These are also used to quantify health inequalities by socio-economic groups to look at how income or socio-economic position affects health.

The SII measures disparities in the PC distribution. First-ranking countries are done based on their socio-economic position, which is generally based on SDI or income level and then it is calculated. It ranks the countries in terms of socio-economic positions using the age-standardized DALY rate. The SII then measures the absolute difference in the burden of disease between the two sections expressed, providing an inequality scale. For instance, a higher SII corresponds to a bigger slant in the distribution of the diseased. SII is calculated using the formula, SII = (rate_high - rate_low) / (n – 1), where rate_high and rate_low are the DALY rates of the highest and lowest socio-economic groups, respectively, and n is the number of socio-economic categories [13]. This assumes linear trends in inequality, which may not fully capture non-linear dynamics in regions with rapid epidemiological shifts; alternative models like polynomial or spline regression could be tested in future studies to assess this [13]. For example, SII has been widely applied in studies of cardiovascular disease to reveal disparities across income gradients [13]. To improve the discriminatory power of comparisons, we recalculated the SII as the Relative Index of Inequality (RII), defined as RII = (rate_high - rate_low) / global age-adjusted DALY rate [13].

The CI measures relative inequality using a Lorenz concentration curve based on DALYs accumulated and population. The CI measures the extent to which the disease burden is disproportionately concentrated in either high or low socio-economic groups. It is calculated by plotting the cumulative percentage of the population on the x-axis against the cumulative percentage of DALYs on the y-axis, then calculating the area between this curve and the line of perfect equality [14]. Specifically, CI = 2 / μ × (area under the Lorenz curve – 0.5), where μ is the mean DALY rate across the population [14]. The disease burden distribution is indicated by the CI that ranges from

−1 to 1 [15]. For instance, CI has been used to assess tuberculosis burden, showing higher concentration in lower-income groups. In the present report, a negative CI value indicates a shift of the PC burden toward countries with lower SDI, as reflected in the estimates [16]. These methods make it possible to examine the variations seen across different regions of the world regarding the burden of PC as well as the influence of socioeconomic status on health.

Results

The global burden of pancreatic cancer

Data from 2021 indicate that PC remains a significant global health challenge, with a significant disease burden that is heavily linked to several risk factors. The number of DALYs related to PC increased significantly from 1.76 million in 1990 to 4.25 million (95% UI 2.06 to 6.46) in 2021. This escalation is underscored by a notable rise in DALY rate, which increased from 32.96 in 1990 to 53.80 in 2021, reflecting a growth of 63.23%. Additionally, the age-standardized DALY rate experienced a modest increase from 43.66 to 48.71, marking an 11.57% rise over the same period (Table 1).

Risk factors contributing to the burden of pancreatic cancer

The two risk variables with the largest increases in related costs were high fasting plasma glucose and high body mass index. High fasting plasma glucose, a key contributor to metabolic syndrome and diabetes, was linked to a 208.99% increase in DALYs. The DALY rate due to this factor rose by 109.30%, from 16.66 to 34.87. Similarly, high body mass index, associated with increased inflammation and metabolic dysfunction, saw a dramatic rise in impact, with DALYs increasing by 1,000% and the DALY rate rising by 590.24%, from 0.41 in 1990 to 2.83 in 2021. This surge may reflect rising obesity prevalence and its metabolic consequences. In contrast, the burden from smoking rose more moderately, with DALYs increasing by 73.79% and the DALY rate by 17.39%, indicating a significant but lesser impact compared to other risk factors. This trend likely reflects the effectiveness of tobacco control policies in certain regions (Table 1). The burden of PC and its associated risk factors in 1990 and 2021 across five SDI groups and 21 GBD regions can be found in Supplementary Table 1.

Gender and age differences in pancreatic cancer burden

There were obvious gender and age differences in PC burden (Figs. 1 and 2). Detailed analysis shows that women were exposed to slightly higher burdens associated with risk factors like high fasting plasma glucose and high body mass index. This can be explained by disparities in biology, such as hormonal differences that influence

Table 1 Global burden of pancreatic cancer and associated risk factors in 1990 and 2021

	DALYs (million)			DALY rate			Age-standardized DALY rate (per100,000)		
	1990(million)	2021(million)	Change (%)	1990(per100,000)	2021(per100,000)	Change (%)	1990(per100,000)	2021(per100,000)	Change (%)
All risk factors	1.76(2.50,1.07)	4.25(6.46,2.06)	141.48	32.96(46.78,20.13)	53.80(81.87,26.04)	63.23	43.66(62.49,26.08)	48.71(74.33,23.43)	11.57
Smoking	1.03(1.12,0.94)	1.79(2.04,1.57)	73.79	19.32(21.09,17.55)	22.68(25.88,19.86)	17.39	24.98(27.32,22.66)	20.38(23.25,17.84)	−18.41
High fasting plasma glucose	0.89(1.75,0.10)	2.75(5.20,0.32)	208.99	16.66(32.79,1.90)	34.87(65.91,4.00)	109.30	22.64(44.60,2.58)	31.70(59.90,3.63)	40.02
High body-mass index	0.02(0.14,−0.05)	0.22(0.63,−0.05)	1000	0.41(2.65,−0.93)	2.83(7.94,−0.61)	590.24	0.55(3.53,−1.24)	2.54(7.16,−0.56)	361.82

DALYs, disability-adjusted life-years

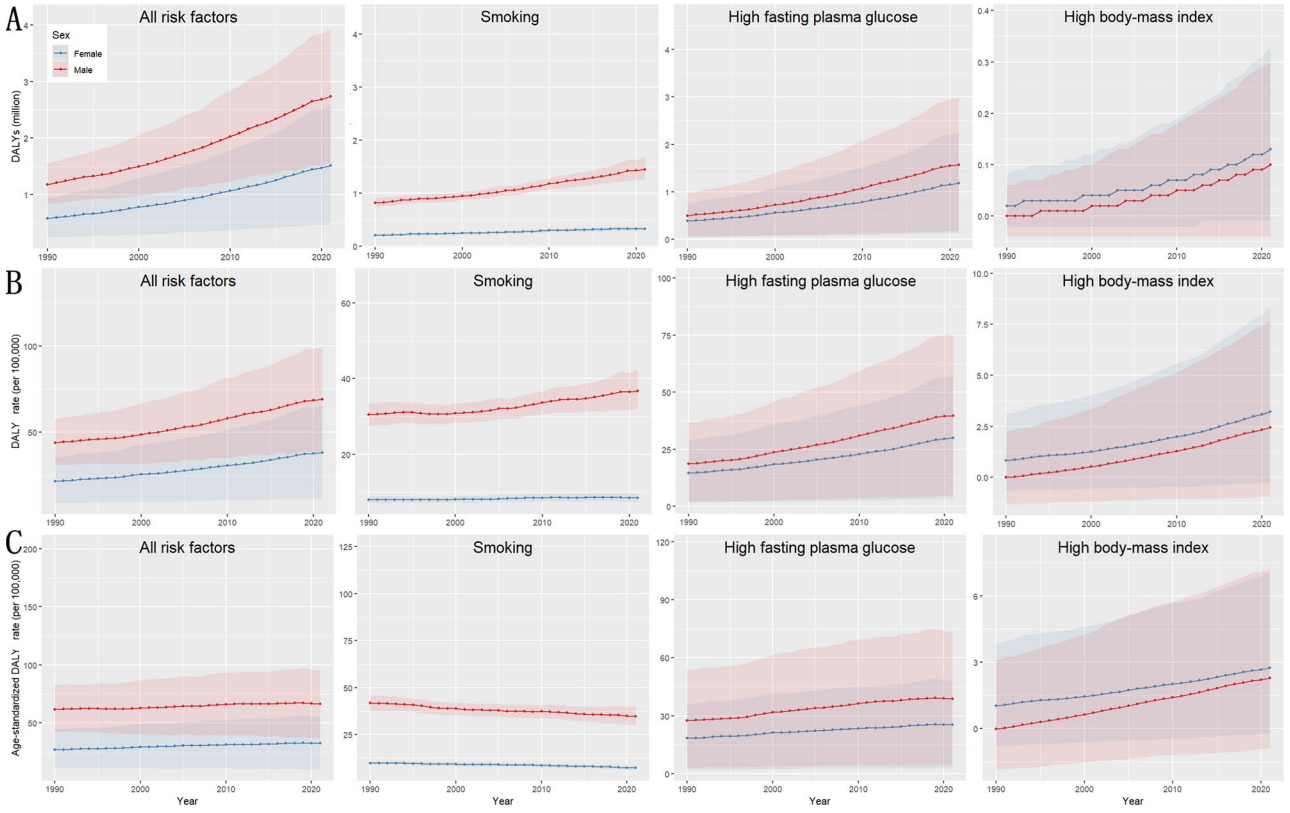

Fig. 1 Global burden of pancreatic cancer by type and sex

metabolic health, and lifestyle, such as dietary patterns and physical activity levels. Specifically, postmenopausal women often experience hormonal changes that lead to increased insulin resistance and fat accumulation, which may exacerbate the effects of high fasting plasma glucose and high body mass index on PC burden. Moreover, societal and cultural elements, such as differences in healthcare-seeking behavior and access to safe practices, may contribute to these disparities.

With age, the burden of PC increases, reaching its peak in the 70–74 age group (Fig. 2A, C). Furthermore, for DALY rates of PC, both genders exhibited age dependency with higher rates in older populations (Fig. 2B, D). Although PC imposes a higher overall burden of disease on men, the faster rise in DALYs associated with risk factors among women shows the need for public health strategies tailored for both genders. An example is interventions aimed at improving metabolic health in women, particularly in older age groups, that could potentially decrease the growing burden of PC. Additionally, future research should examine how gender, socioeconomic status, and access to healthcare interact to produce these disparities.

The distribution of pancreatic cancer burden

The concentration of PC burden in areas with higher SDI levels highlights the major role of socioeconomic factors. Even in regions of high SDI, the greater burden of DALYs may still be due to various causes despite the advanced healthcare systems. The regions mentioned above vary widely in the prevalence of key risk factors, such as high fasting plasma glucose and high body mass index; this is most likely due to lifestyle-related factors such as high sedentary behavior, unhealthy diet, and obesity. Secondly, as the incidence of PC increases with age, older age groups have a higher proportion of cases, a feature commonly observed in high SDI areas. Although advanced healthcare systems improve survival rates for many diseases, PC remains challenging to diagnose early and treat effectively, leading to persistently high DALY rates. Finally, the higher detection rates in high SDI countries due to enhanced surveillance and diagnostic capabilities may also contribute to the observed burden.

In 2021, the most impacted areas globally were East Asia, Western Europe, high-income North America, and high-income Asia Pacific, where the prevalence of risk factors such as high fasting plasma glucose and high body mass index was notably higher (Figs. 3 and 4). China (2.93 million, 95% UI 2.30 to 3.58 million), the United States (1.19 million, 95% UI 1.12 to 1.24 million),

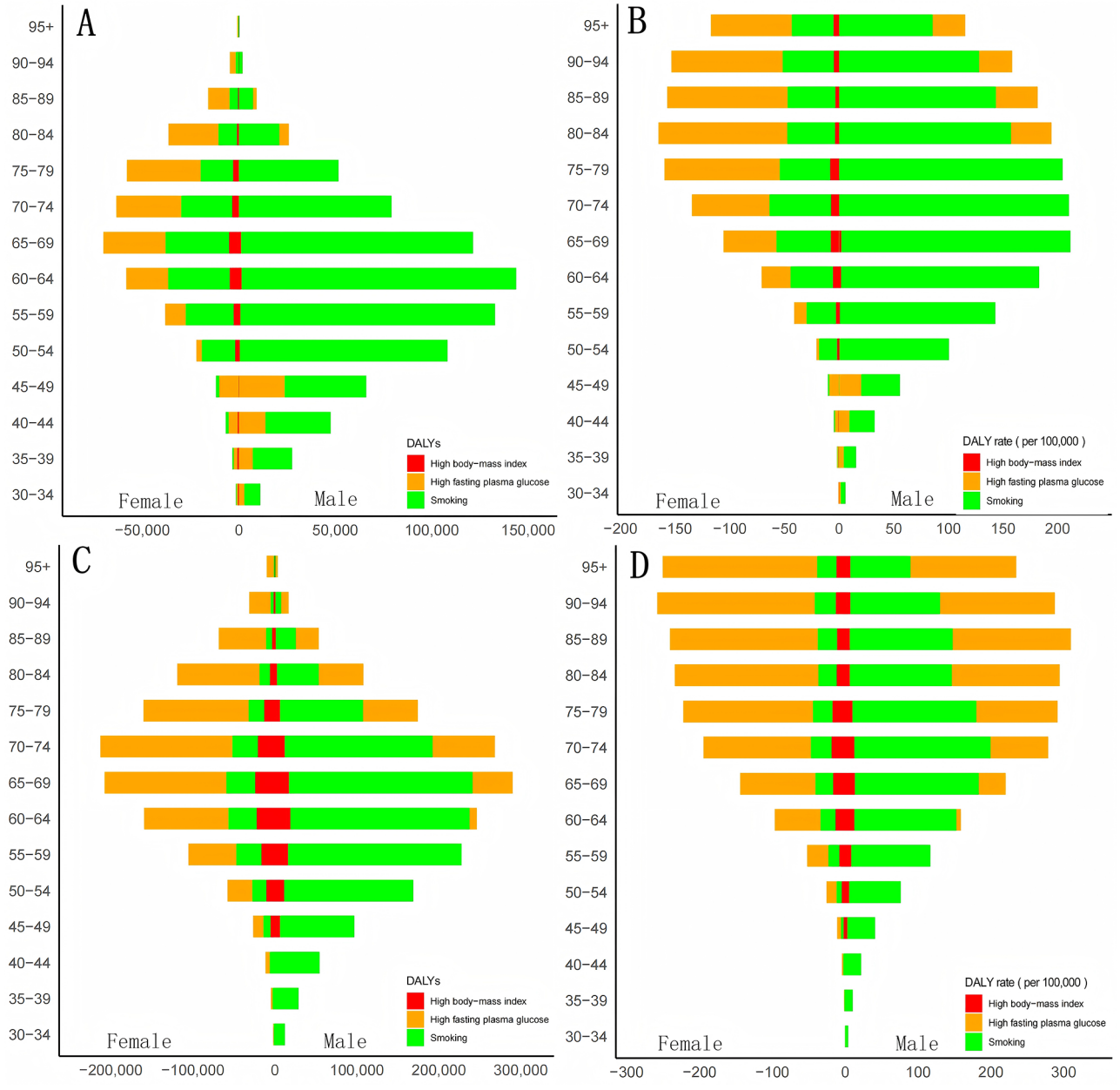

Fig. 2 Age Distribution of Pancreatic Cancer Burden by Sex in 1990 (**A**, **B**) and 2021 (**C**, **D**), Presented as DALYs (**A**, **C**) and DALY Rate (**B**, **D**)

Japan (0.71 million, 95% UI 0.63 to 0.76 million), Russia (0.52 million, 95% UI 0.48 to 0.56 million), India (0.46 million, 95% UI 0.41 to 0.52 million), and Germany (0.41 million, 95% UI 0.38 to 0.44 million) were the six nations that carried the heaviest burden in 2021 at the national level (Fig. 5C).

Compared with 1990, the PC burden in DALYs rose significantly. By 2021, there was an increase of 141.48% in DALYs related to PC, although the overall pattern of geographic distribution remained largely unchanged (Fig. 5A, C). This consistency highlights the sustained impact of socio-demographic and lifestyle factors in these areas.

The regions with the highest age-standardized DALY rates per 100,000 were a mix of transitional, developing, and high-income economies.The five regions that have the highest age-standardized DALY rates were Central Europe, Eastern Europe, High-income North America, Southern Latin America, Western Europe. From the year 1990 to 2021, most Global Burden of Disease (GBD) areas had a significant decrease in age-standardized DALY rates for PC. Several Asian and African nations, however, continued to report high rates during this time,

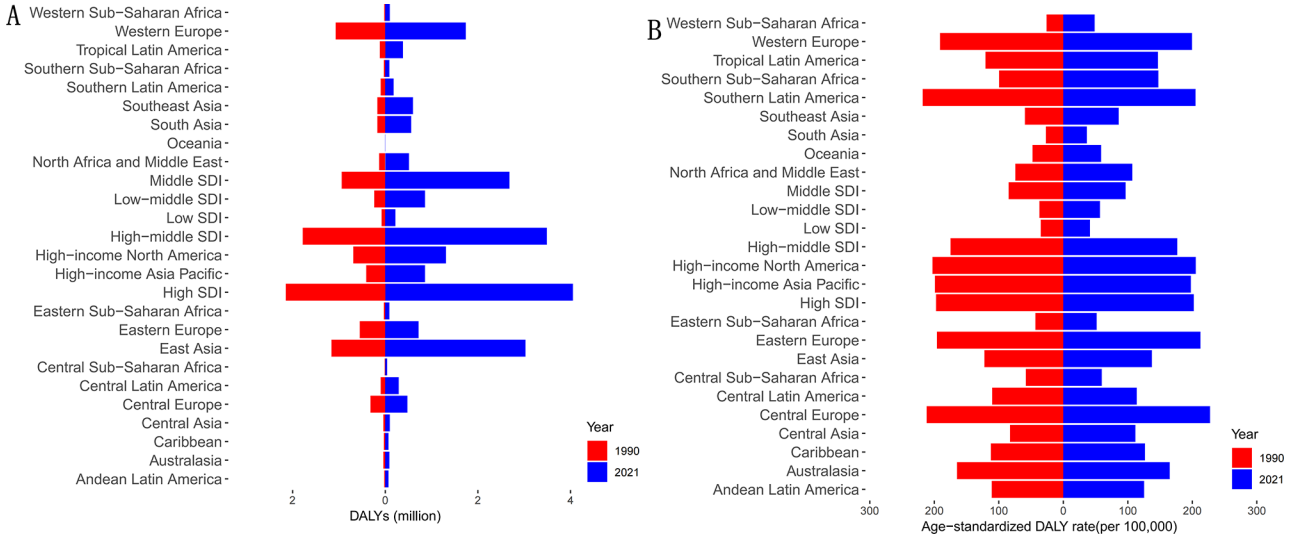

Fig. 3 Regional Changes in Pancreatic Cancer Burden, 1990 vs. 2021 (**A**, **B**)

underscoring persisting public health issues (Fig. 5B, D; Table 2). The top 10 countries with the highest age-standardized DALY rates for PC in 1990 and 2021 are presented in Supplementary Table 2.

Cross-national inequality in pancreatic cancer burden

In both 1990 and 2021, the DALYs SII (per 100,000 people) revealed a marked discrepancy in the burden of PC, with values of 189.63 and 321.17, respectively. This increase indicates a stronger association between crude DALY rates and changes in SDI over this period (Fig. 6; Table 3). The upward trend suggests an increasing disparity in crude PC burden among countries with differing income levels. Notably, some countries deviated from the expected patterns based on SDI. For example, despite having high SDI levels, certain high-income countries, such as the United States and Germany, exhibited disproportionately high PC burdens, likely due to the high prevalence of risk factors like obesity and sedentary lifestyles. Conversely, some LMICs, such as India and China, showed a lower-than-expected burden relative to their SDI, possibly reflecting differences in dietary patterns, physical activity levels, or early-stage interventions targeting metabolic risk factors.

The CI for both DALYs and deaths decreased slightly from 1990 to 2021, indicating a modest reduction in disparity, although low SDI regions continue to bear a disproportionately high burden (Fig. 7). This suggests that while there has been some progress in reducing inequality, significant gaps remain, especially in low SDI regions. Public health policies should focus on addressing these disparities through targeted interventions aimed at improving healthcare access, early detection, and prevention, particularly in countries with lower SDI. These findings underscore that while PC remains a global health challenge, persistent inequities in lower SDI regions call for targeted public health strategies. The unexpected trends observed in certain countries highlight the need for further research to better understand the complex interplay between socioeconomic development, lifestyle factors, and healthcare access in shaping PC burden.

Discussion

Global trends in pancreatic cancer burden

This research presents further concerns about the trends of the global disease burden of PC, specifically the number of DALYs in the past three decades since 1990.The increase is due to the growing prevalence of the disease. Another reason is the growing impact of preventable factors like high fasting plasma glucose and increasing body mass index. Observational data suggest that obesity and diabetes are widely recognized as major modifiable risk factors associated with PC, though causality remains under investigation [17]. Public health interventions targeting these factors have proven effective in some countries but remain underdeveloped in many lower SDI regions due to limited healthcare resources and infrastructure. While the study effectively employs SDI as a stratification tool, it does not fully address key confounders such as genetic predisposition (e.g., BRCA1/2 mutations), environmental exposures (e.g., pollution), and healthcare infrastructure quality, which could influence observed disparities and should be explored in sensitivity analyses [18, 19]. Expanding access to healthcare programs could help close these gaps. It could also lead to better health outcomes worldwide [20]. Data collection is another problem in many LMICs. In these regions, healthcare services in these areas are limited. Reporting is often incomplete, and many cases go uncounted.

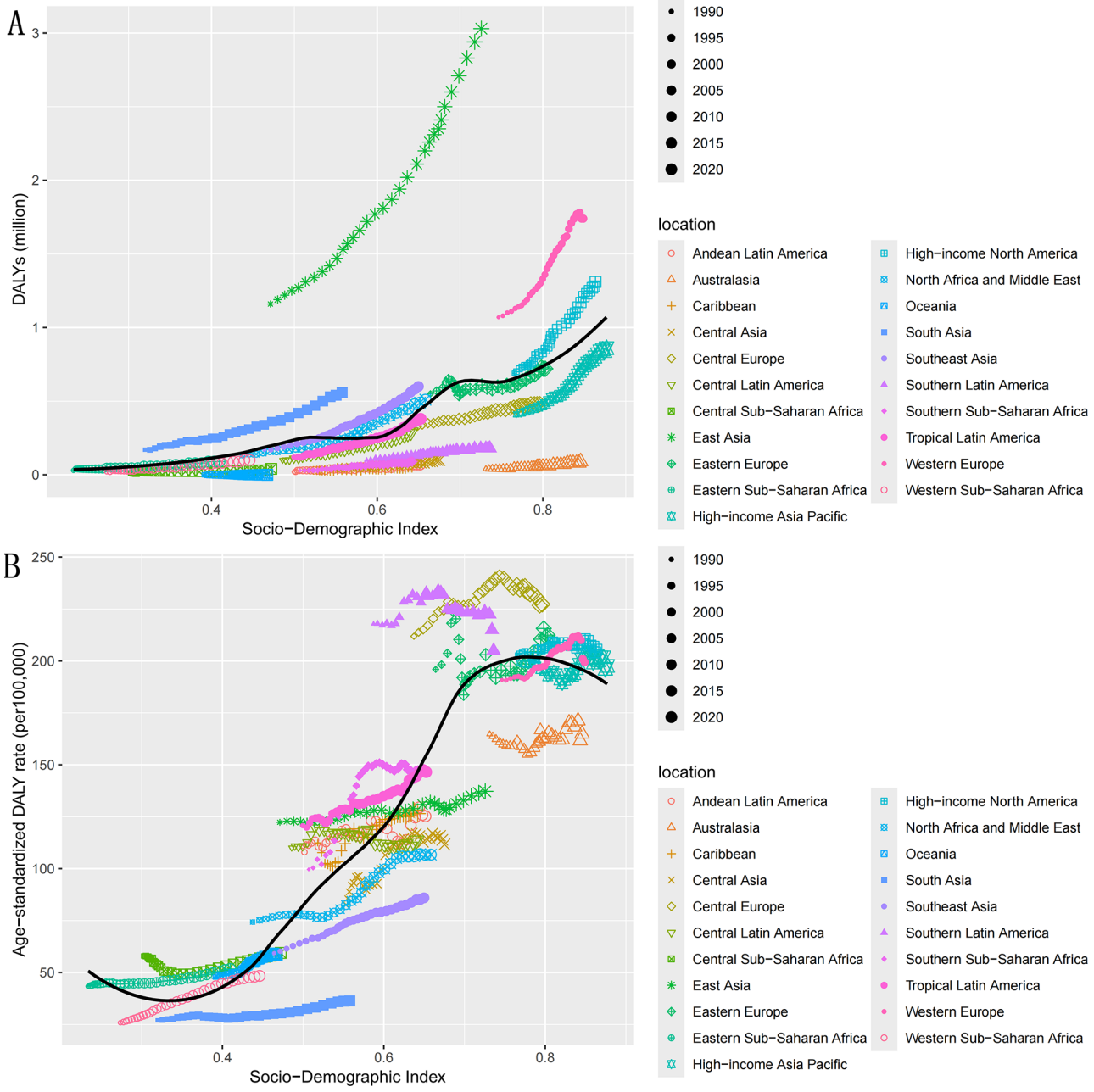

Fig. 4 Global Burden of Pancreatic Cancer Across 21 GBD Regions by SDI, 1990–2020.; (**A**) DALYs; (**B**) Age-Standardized DALY Rate

This makes it hard to understand the true impact of the disease.

Policy implications

To reduce the global burden of PC, a multi-faceted approach is essential. At the community level, health education campaigns and mobile health clinics can raise awareness of modifiable risk factors like obesity, diabetes, and smoking, while improving early detection in underserved areas [21]. National policies, such as sugar taxes, subsidies for healthy foods, and smoking cessation programs, have proven effective in reducing related risk factors and could be expanded to target PC [22, 23]. Integrating PC prevention into existing non-communicable disease (NCD) frameworks, such as the WHO Global Action Plan, can further enhance resource allocation and program efficiency [24, 25].

International collaboration is also critical. High-income countries can support LMICs through funding, technology transfer, and capacity-building initiatives. Programs like the Global Alliance for Chronic Diseases (GACD)

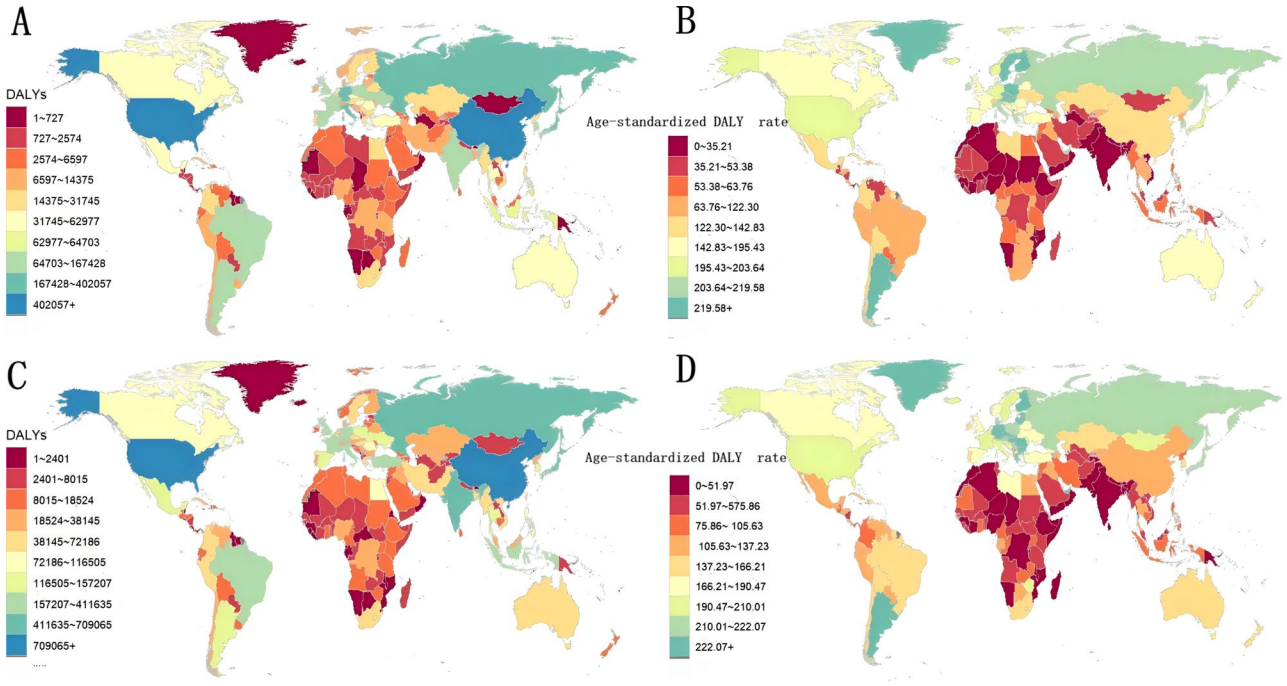

Fig. 5 Spatial Distribution of Pancreatic Cancer Burden in Terms of DALYs (**A**, **C**) and Age-Standardized DALY Rate (**B**, **D**) Across All Age Groups. Note: Certain regions, such as Central Europe, Eastern Europe, High-income North America, Southern Latin America, and Western Europe, continue to exhibit high age-standardized DALY rates due to factors such as aging populations, higher prevalence of risk factors like obesity and smoking, and advanced diagnostic capabilities leading to better disease reporting. These trends highlight the double burden of pancreatic cancer in both high SDI regions, due to lifestyle factors, and low SDI regions, due to inadequate healthcare access

offer replicable models for addressing PC risk factors in resource-limited settings [26, 27].

Focus on modifiable risk factors

Although medical management has improved, modifiable risk factors should still be a major focus for public health efforts. Studies have shown that weight control and diabetes prevention are associated with a lower burden of PC, especially in high-risk populations. As this is an observational study, these relationships reflect associations rather than causal effects. Terms implying causality have been adjusted accordingly. These two factors are correlated with the future incidence of PC.

By comparing studies on other cancers, global trends in PC risk factors can be better understood. For example, research has shown that early screening for colorectal cancer decreases mortality in high-income areas. When colonoscopy screening and treatment were performed in populations, colorectal cancer mortality decreased significantly [28]. Although this success implies the feasibility of screening strategies, PC poses a challenge due to the asymptomatic early stages and the lack of validated population-level screening tools. In contrast to colorectal cancer, which benefits from early screening and clear diagnostic methods, PC requires focus on modifiable risk factors due to the challenges in early-stage detection. Therefore, efforts should prioritize modifiable risk factors such as obesity, diabetes, and tobacco use, which are well-documented in the literature [29].

Cervical cancer also illustrates the impact of preventive strategies. Australia introduced the first cervical cancer vaccination program in 2007, after which incidence and mortality declined [30]. The success highlights the potential of preventive measures for PC by focusing on risk factor control. Tobacco use is a common risk factor for both PC and lung cancer. Strict anti-smoking policies have significantly reduced lung cancer incidence in many countries, and similar benefits may apply to PC prevention given smoking's established role in PC [31]. Unhealthy diets and lack of physical activity are also modifiable contributors to the global PC burden. For example, a meta-analysis of 12 cohort studies demonstrated a 20–30% increased risk of PC associated with obesity, and a 1.5- to 2-fold increased risk with diabetes [32, 33].

Regional differences

Differences in healthcare systems also affect the regional burden of PC. High SDI regions, such as North America and East Asia, usually have more advanced healthcare systems that contribute more to the detection and treatment of cancer patients, including PC, at an earlier stage [7]. On the other hand, in low SDI areas, there is less preventive care and limited diagnostic capacity. While the study effectively highlights global disparities

Table 2 Age-standardized DALY rate of pancreatic cancer across global, five SDI groups, and 21 regions in 1990 and 2021

Location	Age-standardized DALY rate (per100,000)		Change (%)
	1990(per100,000)	2021(per100,000)	
Global	129.32(122.98,135.98)	130.33(120.52,140.13)	0.78
High SDI	197.13(189.39,202.05)	202.04(188.27,212.61)	2.49
High-middle SDI	174.68(164.79,185.04)	176.7(158.07,195.43)	1.16
Middle SDI	84.6(77.1,92.93)	96.61(85.18,108.88)	14.20
Low-middle SDI	36.99(31.34,43.21)	56.78(52.66,61.42)	53.48
Low SDI	34.82(27.01,41.7)	41.21(34.19,49.79)	18.34
Andean Latin America	110.79(92.1,130.15)	125.21(96.38,157.38)	13.02
Australasia	164.74(157.34,171.52)	164.91(153.05,175.07)	0.11
Caribbean	112.4(105.01,119.69)	126.5(110.7,144.06)	12.55
Central Asia	82.67(72.92,95.77)	111.64(97.94,125.6)	35.03
Central Europe	211.89(203.47,219.53)	227.27(208.75,246.43)	7.26
Central Latin America	110.06(107.26,112.7)	113.65(102.01,126.19)	3.26
Central Sub-Saharan Africa	57.94(47.03,70.38)	59.43(41.04,83.01)	2.58
East Asia	122.31(103.25,142.29)	137.21(109.16,166.03)	12.18
Eastern Europe	195.95(186.46,209.44)	212.43(195.58,230.76)	8.41
Eastern Sub-Saharan Africa	43.35(33.59,53.07)	51.69(41.97,66.27)	19.25
High-income Asia Pacific	199.08(191.03,206.3)	197.6(178.87,210.6)	-0.74
High-income North America	202.85(194.36,207.98)	205.41(194.75,212.77)	1.26
North Africa and Middle East	74.28(60.93,88.16)	106.74(93.76,120.32)	43.70
Oceania	47.84(37.93,61.42)	58.56(47.49,74.75)	22.41
South Asia	26.94(21.24,32.56)	36.38(32.29,40.2)	35.05
Southeast Asia	59.32(51.06,68.04)	85.92(73.82,99.74)	44.86
Southern Latin America	217.82(206.07,231.18)	205.04(192.65,218.3)	-5.87
Southern Sub-Saharan Africa	99.65(85.59,122.16)	147.28(129.76,162.99)	47.79
Tropical Latin America	120.69(115.51,124.62)	146.52(138.52,152.83)	21.41
Western Europe	190.87(183,197.87)	199.42(185.68,210.22)	4.48
Western Sub-Saharan Africa	25.84(22.02,29.74)	48.35(40.2,56.31)	87.10

in PC burden between high and low SDI regions, within-country disparities remain underexplored. For instance, in large, heterogeneous countries like the United States, China, and India, regional variations in healthcare access, urban vs. rural differences, and ethnic-specific risk factors could significantly influence the PC burden. A state/province-level DALY analysis could enhance epidemiological insights and policy relevance [7, 34]. For instance, the article published by Aryannejad et al. (2021) mentioned that low SDI regions do not have adequate access to imaging technologies and specialized healthcare professionals, both essential for PC diagnosis and treatment [34]. Therefore, the age-standardized DALY in these areas continues to be high. This highlights the need for more comprehensive health data collection in low SDI areas, which would help better understand and resolve these health disparities. Although studies of liver cancer in low SDI areas have linked high incidence with hepatitis infection and arsenic-contaminated water sources [35], there is a need to address PC risk factors, especially smoking, obesity, and diabetes, which are common in both high and low SDI regions [36–38], to develop strategies to reduce the health disparities in PC burden globally. As discussed earlier, successful interventions in other diseases—such as HPV vaccination for cervical cancer, colorectal cancer screening, and anti-smoking legislation—have demonstrated the value of targeted public health policies. These approaches also provide valuable insights for addressing PC disparities through strengthened preventive strategies and healthcare infrastructure improvements.

Challenges and opportunities for early screening in low SDI settings

Although early screening has the potential to reduce the burden of PC in low SDI settings, it is hindered by the lack of validated population-level screening tools and remains unfeasible in low SDI countries due to insufficient healthcare infrastructure, high costs, and inadequate personnel [34]. Mobile health clinics and point-of-care testing may also create innovative approaches to increase access to screening in poor regions [38]. PC screening can also be integrated into existing NCD programs, such as diabetes management programs, to improve feasibility through the use of existing resources [37].

International collaboration is critical to supporting early screening efforts. Partnerships with high SDI countries and global health organizations could provide funding, technology transfer, and training for healthcare workers. Pilot programs tailored to local contexts could help identify cost-effective and culturally appropriate screening strategies [38]. While challenges remain, early screening represents a promising avenue for reducing PC burden in low SDI countries [35].

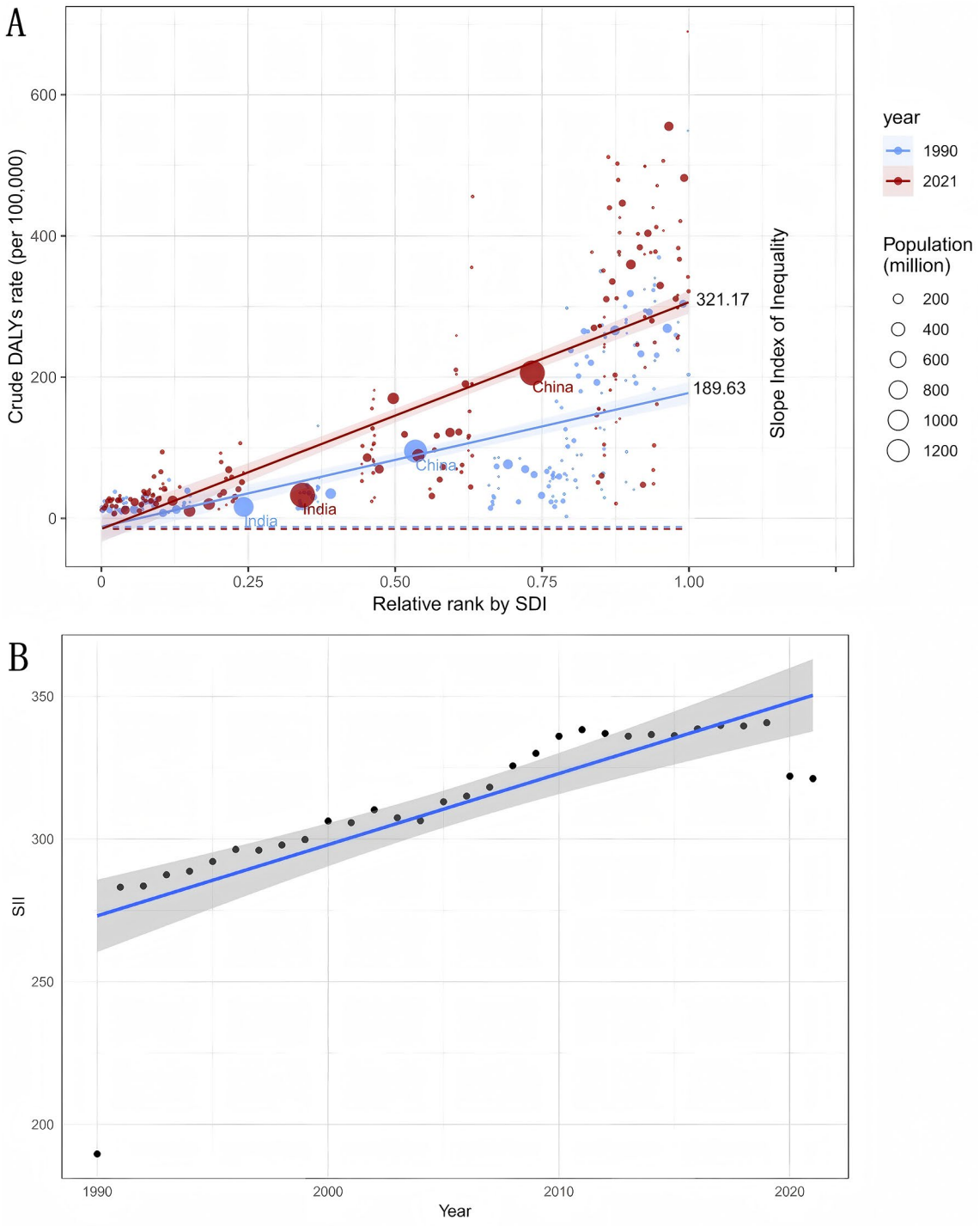

Fig. 6 Slope Index of Inequality (SII) Analysis (**A**) Absolute Income-Related Health Inequality in PC Burden Presented with Regression Lines, 1990 vs. 2021. A higher SII value indicates greater health inequality, signifying that populations with lower socioeconomic status face a disproportionately higher health burden. (**B**) Trend in SII from 1990 to 2021, illustrating changes in health inequality over time. This highlights the importance of targeted public health interventions to reduce disparities

Gender and age considerations

This work also demonstrates the distribution of the burden of PC by gender and age. For instance, women have a slightly higher health risk burden characterized by high body mass index, and fasting plasma glucose, both known to be gender-related health risks. This implies that preventive measures should be designed to capture gender-specific traits [39]. It is also important to note that

Table 3 Trends in the slope index of inequality (SII) from 1990 to 2021

YEAR	1990	1991	1992	1993
SII	189.63(177.65,245.17)	283.1(265.17,364.76)	283.54(264.31,363.01)	287.44(268.83,367.59)
YEAR	1994	1995	1996	1997
SII	288.71(270.43,369.61)	292.11(269.23,367.15)	296.31(270.24,365.95)	296.07(271.62,367.77)
YEAR	1998	1999	2000	2001
SII	297.89(273.46,369.4)	299.8(273.28,367.82)	306.26(278.43,371.75)	305.73(278.83,371.75)
YEAR	2002	2003	2004	2005
SII	310.22(279.92,371.93)	307.46(280.46,371.36)	306.44(280.61,370.91)	313.06(284.94,375.5)
YEAR	2006	2007	2008	2009
SII	315.03(288.72,379.07)	318.17(293.56,384.63)	325.63(300.79,391.38)	330.01(304.58,393.74)
YEAR	2010	2011	2012	2013
SII	336.03(308.46,397.19)	338.29(309.54,396.85)	336.99(308.76,396.28)	336.05(309.12,395.92)
YEAR	2014	2015	2016	2017
SII	336.58(309.56,396.51)	336.24(310.23,397.08)	338.6(308.73,396.12)	339.77(311.15,397.67)
YEAR	2018	2019	2020	2021
SII	339.6(310.74,398.24)	340.73(310.48,397.16)	322.02(297.25,382.61)	321.17(294.48,379.72)

a greater burden is borne by older generations. As far as prevention is concerned, it would be beneficial to start with the middle-aged population before they enter these high-risk age groups [40].

Geographic and genetic influences

This study also identifies geographic differences as another important factor to consider. East Asia, Western Europe, high-income North America, and high-income Asia-Pacific contribute most of the DALYs, primarily due to large populations and greater exposure to risk factors [41]. However, genetic predispositions, such as BRCA1/2 mutations, also contribute to the burden in these regions, while environmental factors, such as urbanization and dietary shifts play a more prominent role in transitional economies [18].

In high SDI regions, genetic predispositions like BRCA1/2 mutations significantly contribute to PC burden, particularly in populations with a family history of the disease [18]. These genetic risks tend to manifest in the context of environmental factors, including urbanization, sedentary behavior, and unhealthy dietary patterns, which may exacerbate them [19]. Conversely, these risks can be mitigated by healthier lifestyles and better access to preventive care. The interplay underlines the necessity of integrated prevention strategies aimed at both genetic and lifestyle risk factors.

One strategy to reduce risk would be genetic screening programs in high SDI regions so that individuals at higher risk could be identified by targeted interventions such as enhanced surveillance [42]. However, the problem should be addressed with consideration of the ethical, social, and economic implications to ensure equitable access and prevent stigmatization.

Socioeconomic determinants and international disparities

This highlights the interaction between genetic and environmental factors in driving regional trends. Nevertheless, the study also shows persistently high levels of age-standardized DALY rates in the lower-income and transition countries, especially Asian and African nations [43]. This is quite telling and gives a message that more emphasis should be placed on social economic determinants of health. Policy approaches should integrate SDI-adjusted strategies that combine public health interventions in high SDI areas with socio-economic improvements in low SDI regions. For example, the successful of diabetes management and weight reduction programs in high SDI countries can serve as models for resource-limited regions, which urgently need investments in education, nutrition, and access to healthcare services. The Diabetes Prevention Program (DPP) launched in the United States in 1996 and Japan's weight management initiative introduced in 2008 significantly reduced the incidence of obesity- and diabetes-related cancers through interventions targeting diabetes management and weight reduction [44]. These success stories offer replicable frameworks for other nations.

People in the low SDI nations are still bearing a higher age-standardized DALY rate for any given year, which indicates that life expectancy is still linked strongly with the socio-economic standing of populations. This underscores the lack of sufficient interventions aimed at addressing the social determinants of health in these areas. Greater socio-economic interventions are needed to improve health education and access to healthcare services in these regions, thereby reducing health disparities.

The international disparities in SDI between 1990 and 2021 suggest the rising role of socioeconomic determinants of health [45]. The developed nations usually get better healthcare units with improved resource

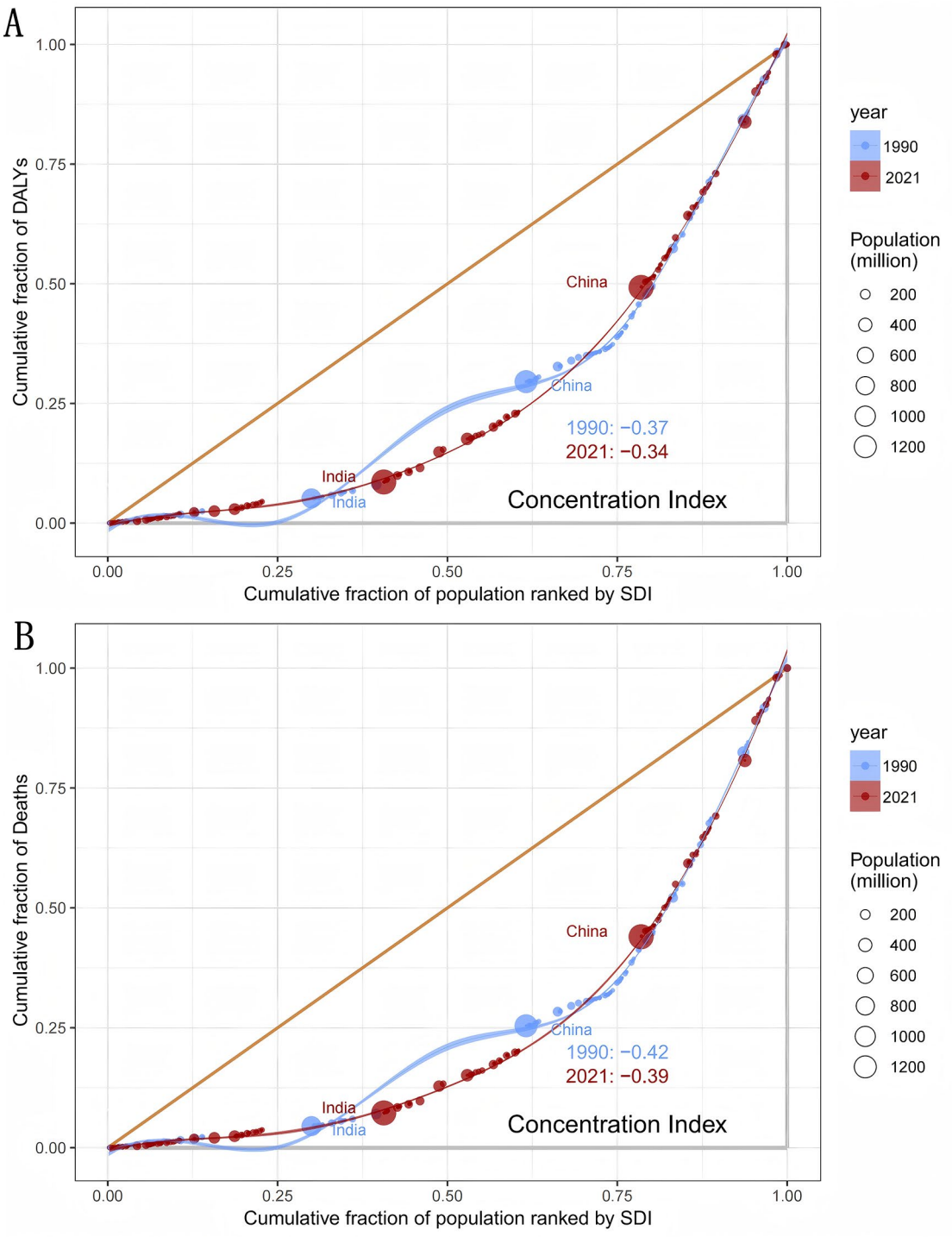

Fig. 7 Concentration Index Analysis: Relative Income-Related Health Inequality in PC Burden Presented with Concentration Curves, 1990 vs. 2021; (**A**) Cumulative Fraction of DALYs; (**B**) Cumulative Fraction of Deaths. The Concentration Index (CI) is the measure of income-related health inequality with higher values implying higher inequality and more burden on wealthier population. Pancreatic cancer burden (DALYs and deaths) concentration curves are presented according to various income groups. Thus, this figure shows the trends from 1990 to 2021 showing the changes in health inequality over time

endowment toward both prevention and treatment. Nevertheless, lower-income countries still have many problems concerning public health, limited access to high-quality and preventive healthcare, and early-phase screening programs. With the large income and healthcare access divide between these areas, the disease burden of PC remains high. This underscores the need for international collaborations to harmonize responses to PC and reduce health inequities.

Limitations and future directions

However, there are several limitations that have to be discussed despite the numerous insights provided by the 2021 GBD study. First, regarding data collection, the assessment of the disease burden may not fully reflect the real situation, particularly in economically underdeveloped regions where data availability is scarce and underreporting is common. This can lead to biases in estimating disease burdens [46]. Challenges include the missing comprehensive health system records and differences in methods of reporting. We recommend implementing standardized surveys of health like repeated, structured annual village surveys by trained local healthcare workers to collect health data and to report the findings to the district health department; capacity building initiatives such as instilling the skill to collect and reporting health data in the local healthcare workers as a strategy to mitigate these challenges [47]. Future research should also explore the integration of digital health technologies, mobile data collection tools, and community-based health surveillance systems to improve data completeness and timeliness in low SDI regions. In addition, fostering international collaborations to support data infrastructure and health information systems in under-resourced areas may contribute to long-term improvements in data reliability. Furthermore, the lack of subnational data limits our understanding of within-country disparities, such as those in the United States, China, and India, where state/province-level variations could better inform targeted interventions [48]. In future studies, subnational data should be collected and analyzed using methods like spatial regression or geospatial mapping to assess these disparities and reduce uncertainty [48]. The second limitation is the use of secondary data instead of clinical data, which may affect the accuracy of the findings. National-level data does not reflect regional differences, and therefore cannot account for potential underestimations of some disease burdens in specific populations [49]. Moreover, this study did not adjust for variations in healthcare quality or cancer registry coverage, which may further influence the observed burden and represent a key limitation. To obtain a more robust foundation to analyze disease trends, future studies should utilize primary sources, including hospital records or population surveys, in addition to secondary data. Third, the trends in this study may reflect the effects of external factors, such as medical advances in diagnostic technology, increased access to health care, or public health programs. For instance, newly developed diagnostic tools may arbitrarily raise the disease's burden or healthcare supply deficiencies may exacerbate regional variations. Future studies should include sensitivity analyses for these factors and account for confounding variables to obtain a more accurate interpretation of observed patterns. Nevertheless, the GBD study has significantly advanced the standardization and credibility of the data. However, more accurate documentation in future investigations is needed for more complete data [50].

Conclusion

In conclusion, the rising global burden of PC and increasing inequalities necessitate integrated approaches for its prevention and early diagnosis. Strategies should focus on modifiable risk factors and tailored global strategies, particularly in low SDI regions, to reduce health disparities. International funding and targeted interventions, such as capacity building and improved diagnostics access, are crucial. The 2021 GBD study provides a robust foundation for understanding PC burden, despite challenges in data collection. Future studies should focus on improving data collection in underrepresented regions and exploring modifiable and nonmodifiable risk factors to inform prevention strategies. Policymakers are encouraged to integrate these findings into national cancer control plans, with an emphasis on equity-based health interventions. Strengthening healthcare systems and international collaboration will be essential for reducing PC's global burden. (Policy recommendations for reducing the global burden of PC are provided in Supplementary Table 3).

Abbreviations

PC	Pancreatic cancer
DALY	Disability adjusted life years
SDI	Socio-demographic index
GBD	Global Burden of Disease
LMICS	Low- and middle-income countries
UI	Uncertainty interval
CI	Concentration Index
SII	Slope Index of Inequality
RII	Relative Index of Inequality
NCD	Non-communicable Disease
GACD	Global Alliance for Chronic Diseases

Supplementary Information

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Supplementary Material 1

Supplementary Material 2

Supplementary Material 3

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Not applicable.

Author contributions
WL and LR researched and analyzed the data and wrote the paper. ZQ was in charge of data collation. GW and BL assisted in the data analysis and the layout of the paper. GS designed, revised and directed the manuscript. All authors reviewed the manuscript.

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Data availability
The data used in this study came from a public database that everyone can access through the link provided in this article (https://vizhub.healthdata.org/gbd-results/).

Declarations

Ethics approval and consent to participate
The analysis of these anonymized open-source data did not necessitate ethical clearance.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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