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Age-period-cohort analysis of global, regional, and national pancreatic cancer incidence, mortality, and disability-adjusted life years, 1990–2019

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Abstract

Background Pancreatic cancer is one of the deadliest cancers in the world. In recent years, the incidence and mortality rates of pancreatic cancer have shown an increasing trend year by year. This study investigates the independent effects of age, period, and cohort on the global incidence, mortality, and disability-adjusted life years (DALYs) of pancreatic cancer from 1990 to 2019, and evaluates the differences in the burden of pancreatic cancer across regions with different Sociodemographic Index (SDI) levels.

Methods Estimating the impact of age, period, and cohort on pancreatic cancer disease burden in different SDI regions using age-period-cohort modeling with data (with 95% uncertainty intervals [UI]) from the Global Burden of Disease (GBD) Study 2019 and net drift of age-standardized incidence rates (ASIR), age-standardized mortality rates (ASMR), and age-standardized DALY rates (ASDR) for pancreatic cancer in 120 countries.

Results The number of new cases of pancreatic cancer worldwide increased from 197,348 (95% UI: 188,604,203,971) in 1990 to 530,297 (486,175,573,635) in 2019, the number of deaths increased from 198,051 (189,329 to 204,763) in 1990 to 531,107 (491,948 to 566,537) in 2019, and the number of DALY increased from 4,647,207 (4,465,440 to 4,812,129) in 1990 to 11,549,016 (10,777,405 to 1,238,912) in 2019. The ASIR of the average levels in global pancreatic cancer increased from 5.22 (4.97 to 5.40) per 100,000 population to 6.57 (6.00 to 7.09) per 100,000 population, the ASMR increased from 5.34 (5.07 to 5.52) per 100,000 population to 6.62 (6.11 to 7.06) per 100,000 population, and the ASDR increased from 115.47 (110.82 to 119.60) per 100,000 population to 139.61 (130.18 to 149.14) per 100,000 population. The incidence, mortality, and DALY rates of pancreatic cancer increase with age globally and across all SDI regions, peaking in the 85–89 age group. In high and high-middle SDI regions, the growth rate for males is higher than for females before the age of 85, while females have a higher growth rate after 85. The 75–79 age group exhibits the highest DALY rate in high and high-middle SDI regions, significantly higher than the global and other SDI regions. From 1990 to 2019, the period effects of pancreatic cancer incidence, mortality, and DALY rates have increased

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significantly worldwide, while remaining almost unchanged in high and high-middle SDI regions. In contrast, period effects have significantly increased in middle, low-middle, and low SDI regions. Cohort effects are more pronounced in middle, low-middle, and low SDI regions.

Conclusions With the aggravation of population aging, the incidence and mortality rates of pancreatic cancer in the world are increasing, and effective prevention and control measures can be achieved by reducing the exposure of risk factors. The APC model used in our analysis provides a novel approach to understanding the complex trends in the incidence, mortality, and disability-adjusted life years of pancreatic cancer. It can inform the development of targeted interventions to reduce the severe disease burden caused by pancreatic cancer.

Keywords Pancreatic cancer, Age-period-cohort model, Epidemiology, Global burden disease

Introduction

In 2021, it is estimated that there will be 509,000 new cases of pancreatic cancer worldwide, with 505,752 new deaths, ranking it as the 14th most prevalent cancer [1, 2]. When pancreatic cancer was discovered, most individuals were already at an advanced stage. It is estimated that only about 12% of the patients have a survival time of more than 5 years. Therefore, Pancreatic cancer is the deadliest of all cancers [3]. In addition, it is difficult to diagnose because of the difficulty in determining the anatomical location of the pancreas and the lack of biomarkers for early cancer screening, which further increases the difficulty of clinical diagnosis [4, 5]. With the annual increase of pancreatic cancer incidence and mortality, it has brought a huge public health problem to most countries in the world. Therefore, it is crucial to urgently identify and implement novel treatment and prevention strategies, The first step in primary prevention is to identify risk factors and high-risk groups [6, 7].

Globally, nearly half of all pancreatic cancer cases are diagnosed in individuals over the age of 70. with the increase of incidence rate of pancreatic cancer, especially among young people, it will cause serious disease burden [8]. The pathogenesis of pancreatic cancer remains unclear, and compared with other cancers, there are fewer risk factors attributable to genetics and lifestyle, this poses a challenge for the early detection of pancreatic cancer [9]. With the growth of age, the incidence of pancreatic cancer in most elderly people is related to gene mutation, and genetic and lifestyle factors may be more closely related to early pancreatic cancer [10, 11]. At present, smoking is recognized as the risk factor for pancreatic cancer, followed by high BMI and high fasting plasma glucose. Smokers have 2.5–3.6 times the risk of pancreatic cancer than non-smokers. The risk increases with increased smoking and longer exposure to smoking, so quitting smoking is the most effective strategy for reducing pancreatic cancer risk [12, 13]. The correlation between diabetes and pancreatic cancer is widely acknowledged and long-term diabetes is an important factor in the development of pancreatic cancer [14, 15]. Obesity is also increasingly recognized as a modifiable risk factor for pancreatic cancer [16, 17]. Understanding the potential risk factors will aid in the prevention of pancreatic cancer by reducing exposure and identifying individuals most likely to develop this often fatal cancer.

To assess the effects of age, period, and birth cohort on pancreatic cancer incidence, mortality, and disability-adjusted life years (DALY), this study analyzed three dimensions based on the age-period-cohort model. Age effect reflects the internal influence of different age groups on pancreatic cancer. Period effect reflects the influence of public health intervention measures, health education policies and treatment methods on the development of pancreatic cancer. Birth cohort effect refers to different exposure risks due to different degrees of social, natural and environmental factors due to different birth years. From 1990 to 2019, we conducted a comprehensive analysis of the global disease burden of pancreatic cancer, considering variations in gender, regions, and countries. Additionally, we examined the age-standardized incidence rate (ASIR), age-standardized mortality rate (ASMR), and age-standardized DALY rate (ASDR) across different socio-demographic index (SDI) regions. These findings serve as a robust foundation for the development of effective strategies in the prevention and treatment of pancreatic cancer.

Methods

Data sources

Global Burden of Disease (GBD) Study 2019 database employed a standardized approach to evaluate the disease burden of 369 health conditions and 87 risk factors across 204 countries and regions globally. The data sources of GBD estimation process include population census, household surveys, disease registration, health services, air pollution monitoring, satellite imaging, etc. [18, 19]. The GBD study is currently the largest and most authoritative disease burden study internationally, and its results provide scientific and transparent evidence for the allocation of health resources in different countries around the world [18]. The GBD study utilizes the Bayesian meta-regression modeling tool DisMod-MR 2.1, which incorporates comprehensive data from various sources, including temporal, age-related, and geographical factors, as well as health causes and domains. This approach enables the estimation of incidence, mortality, and DALY rates for a wide range of health conditions. It is revised based on simulation research, allowing estimates from existing data for countries without data sources, providing prior information for areas with limited information can help improve the coverage of uncertainty interval (UI) [20]. All disease estimates for GBD include a 95% UI, which is based on the 975th and 1000th ordered values of the 25th posterior distribution. This article selects " Pancreatic cancer” as the research disease, and “Incidence, Deaths, DALY” as the analysis indicators. DALY represents the cumulative measure of years of healthy life lost due to disability or premature death from the onset of a health condition until death. The SDI quintile values categorize countries or regions into five groups: high SDI, high-middle SDI, middle SDI, low-middle SDI, and low SDI. A region with an SDI of 0 represents the theoretical minimum level of development relevant to health, while a region with an SDI of 1 represents the theoretical maximum level. The SDI is divided according to national income per capita, average years of schooling for those aged 15 years and older, and total fertility rate [21].

Statistical analysis

We calculated the proportion of deaths and DALYs in 2019 attributable to three recognized risk factors for pancreatic cancer: smoking, high fasting plasma glucose, and body mass index (BMI). This research employs the age-period-cohort model to examine the potential influence of age, period, and birth cohort on the incidence, mortality, and DALY of pancreatic cancer. The age-period-cohort model is a statistical analysis method used to decompose and analyze the incidence or mortality rates of diseases or other events over time. This model breaks down the time dimension into three independent components: age, period, and cohort. The age-period-cohort model surpasses conventional epidemiological analysis techniques and is extensively utilized for population-level analysis of tumor incidence and mortality rates [22]. Usually, the age-period-cohort model is based on the generalized linear model theory and quantifies the additive effects of age, period, and birth cohort. Generally, additive effects can be divided into linear and nonlinear components [23, 24]. Because of the collinearity among age, period, and cohort, it is statistically infeasible to estimate their individual effects, thus there has always been a problem with model recognition. We avoid this problem by generating a new estimable function called fitting the onset age curve and extrapolating the observed age specific ratios of the entire birth cohort by constructing a fitting curve to estimate the past, current, and future ratios of the current cohort [25]. In the age-period-cohort model, the age effect refers to the differences in the burden of disease among different age groups due to factors such as accumulation of social experience and changes in social roles, the period effect reflects the changes in the impact of social, economic, cultural, and demographic factors on all age groups over time, and the cohort effect represents the changes in the impact of temporal differences in the experience of the initiating event on all groups [26]. Typically, the age period queue model can be represented as $\log(M) = \mu + \alpha i + \beta j + \gamma k + \varepsilon$ Where, M is the incidence /mortality/DALY rates of pancreatic cancer; μ is the intercept term; αi is the age effect of the ith age group; βj represents the period effect of the jth period; γk represents the queue effect of the kth queue; ε Represents a random error term. Webpage analysis tool based on GBD 2019 data and age-period-cohort model. This study selected global, regional, and national incidence, mortality, and DALY data for pancreatic cancer at 5-year intervals as one time period. As there were no data available for pancreatic cancer in individuals under 15 years of age, this study excluded data for this age group. The study included 17 age groups, ranging from “15–19” to “≥95” years, with each age group spanning 5 years. The study divided the years 1990–2019 into six periods, each consisting of five years, for the purpose of period analysis. Similarly, the birth cohorts were divided into 22 groups, each spanning five years, from “1895–1899” to “2000–2004”. The fitted age-period-cohort model estimated the overall temporal trends in incidence, mortality, and DALY rates, also known as net drift, which is the average annual change percentage (AAPC) in the logarithmic value of the disease rate adjusted for period and cohort effects. The model also estimated the local drift, which is the annual percentage change (APC) in the logarithmic value of period and cohort effects for each age group [26].

Results

Major causes of death and DALY in pancreatic cancer worldwide

Globally and across different SDI regions, the primary contributors to pancreatic cancer deaths and DALYs in 2019 were tobacco use, high fasting plasma glucose, and high BMI, in descending order. Tobacco caused 113,384 pancreatic cancer deaths globally (95%UI:98,830 to 128,466), accounting for more than 50% of all deaths (Fig. 1).

Global, regional, and national trends in pancreatic cancer incidence, mortality, and DALY from 1990 to 2019

Globally, the number of new pancreatic cancer cases, deaths, and DALY increased in 2019 compared to 1990. Specifically, the number of new cases of pancreatic cancer rose from 197,348 (188,604 to 203,971) in 1990 to

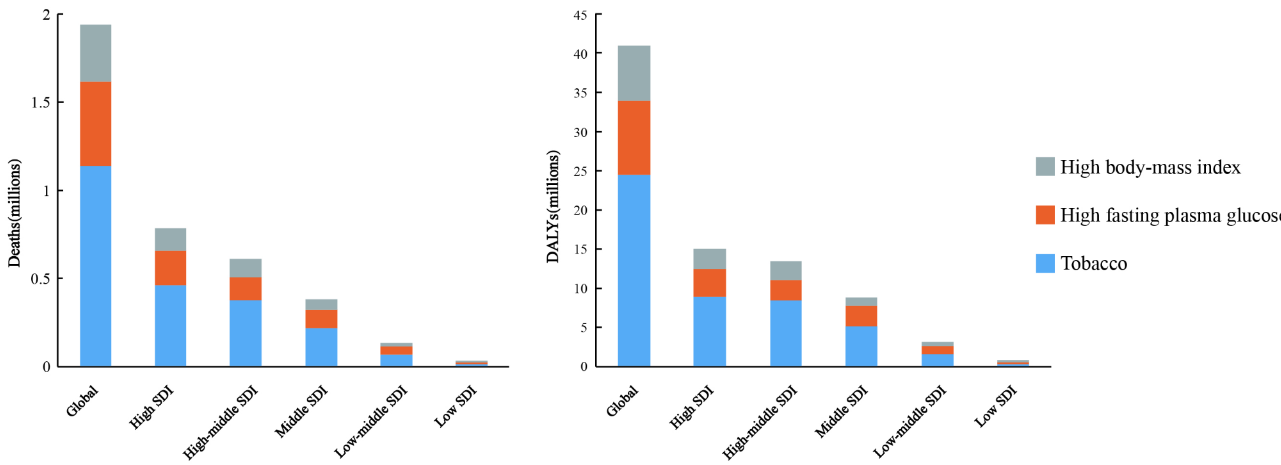

Fig. 1 The main causes of death and DALY of pancreatic cancer in the world. (**A**) The number of pancreatic cancer deaths caused by different risk factors in 2019. (**B**) The person-year of DALY of pancreatic cancer caused by different risk factors in 2019

530,297 (486,175 to 573,635) in 2019. and the number of deaths increased from 198,051 (189,329 to 204,763) in 1990 to 531,107 (491,948 to 566,537) in 2019, DALY has more than doubled from 4,647,207 person years in 1990 (4,465,440 to 4,812,129) to 11,549,016 person years in 2019 (10,777,405 to 12,338,912). From 1990 to 2019, ASIR of pancreatic cancer in the world increased from 5.22 (4.97 to 5.40) per 100,000 population to 6.57 (6.00 to 7.09) per 100,000 population, an increase of 25.9%, ASMR increased from 5.34 (5.07 to 5.52) per 100,000 population to 6.62 (6.11,7.06) per 100,000 population, an increase of 24.0%, and the ASDR increased from 115.47 (110.82 to 119.60) per 100,000 population to 139.61 (130.18 to 149.14) per 100,000 population, an increase of 20.9%. Among different SDI regions, in 2019, ASIR, ASMR, and ASDR in low-middle SDI regions increased the most significantly compared with 1990, increasing by 97.8%, 96.3% and 90.7% respectively, while the growth rate in high SDI regions was the lowest, increasing by 17.2%, 13.1% and 8.2% respectively. Net drift was higher in low-mid SDI areas than in other areas, and the net drift in ASIR, ASMR, ASDR are 2.17% (2.10 to 2.24), 2.17% (2.10 to 2.24) and 2.16% (2.09 to 2.23) respectively (Table 1).

Among 204 countries and regions, in 2019, ASIR, ASMR of pancreatic cancer in Greenland and Monaco were the highest, ASIR, ASMR in Ethiopia, Somalia and Papua New Guinea were the lowest, ASDR in 2019 were the highest in Greenland and the United Arab Emirates (Fig S1, Fig S2, Fig. 2). Countries ranked in the top 120 countries in terms of number of pancreatic cancer incidence, deaths, and DALY were selected for analysis, with China, the United States, and Japan ranking in the top three countries in terms of number of incidence and deaths. During 1990–2019, net drift of ASIR of pancreatic cancer was 1.98% (1.79,2.17), 0.37% (0.27,0.47) and 0.07% (-0.24,0.38), respectively. Net drift of ASMR were 1.88% (1.70, 2.06), 0.28% (0.16, 0.40), and −0.16% (-0.39,0.08), respectively. The top three ASDR are China, the United States, and India, with net drift of 1.86% (1.59,1.12), 0.28% (0.21,0.35), and 2.27% (2.04,2.51), respectively (Table S1).

Effects of age, period, and cohort factors on pancreatic cancer incidence, mortality, and DALY

Fig S3 shows the APC in pancreatic cancer incidence, mortality, and DALY for each age group from 15 to 19 years to 95+years, with the incidence of pancreatic cancer globally trending up for the entire population in all age groups, pancreatic cancer incidence, mortality and DALYs for males are increasing in all age groups. Pancreatic cancer incidence, mortality, and DALY are decreasing for women in the 15–19 and 35–55 age groups in high SDI regions and in the 15–45 age group in middle-high SDI regions. In middle SDI region, only women in the 15–30 age group are showing a downward trend. Pancreatic cancer incidence, mortality, and DALY in all age groups in the low-mid SDI region and the low SDI region show increasing trends and increases with age, and the increases are significantly higher for females than for males.

As shown in Fig. 3, the age-related effects on pancreatic cancer incidence globally and across different SDI regions indicate an initial increase followed by a subsequent decline. The peak incidence occurs in the 85-89-year age group, with the highest increase observed in the high SDI region. Pancreatic cancer mortality increases progressively with age globally and in different SDI regions. Men exhibit a higher growth rate compared to women before the age of 85, while the opposite is observed after the age of 85. DALY rate of pancreatic cancer follows a similar pattern to the incidence rate, showing an initial rise

Table 1 Incidence number, deaths, and DALY for pancreatic cancer in 1990 and 2019 and percentage change of crude and net drift of age standardized rates by location

	Global		High SDI		High-middle SDI		Middle SDI		Low-middle SDI		Low SDI	
	1990	2019	1990	2019	1990	2019	1990	2019	1990	2019	1990	2019
Incidence number	197,348(188,604 to 203,971)	530,297(486,175 to 573,635)	91,157(87,225 to 93,124)	196,919(174,831 to 215,525)	64,779(62,374 to 67,157)	156,543(142,579 to 170,422)	27,405(25,465 to 29,352)	117,095(104,632 to 130,584)	10,304(8,852 to 11,799)	46,939(42,996 to 51,039)	3,632(2,909 to 4,342)	12,561(11,018 to 14,176)
Percent change, %[1]	168.7		116.0		141.7		327.3		355.5		245.8	
ASIR (95% UI)	5.22(4.97to 5.4)	6.57(6.00 to 7.09)	8.67(8.30 to 8.86)	10.16(9.12 to 11.11)	6.14(5.89 to 6.37)	7.67(6.98 to 8.34)	2.72(2.54 to 2.91)	4.80(4.28 to 5.34)	1.79(1.53 to 2.04)	3.54(3.24 to 3.84)	1.59(1.27 to 1.91)	2.54(2.23 to 2.87)
Percent change, %	25.9		17.2		24.9		76.5		97.8		59.7	
Net Drifft(%, per year)[2]	0.66(0.61 to 0.71)		0.38(0.26 to 0.49)		0.55(0.47 to 0.63)		1.70(1.62 to 1.78)		2.17(2.10 to 2.24)		1.59(1.50 to 1.68)	
Death Number	198,051(189,329 to 204,763)	531,107(491,948 to 566,537)	89,795(85,585 to 91,855)	189,782(171,237 to 200,955)	66,079(63,329 to 68,574)	159,583(146,077 to 170,902)	27,840(25,926 to 29,775)	120,021(107,035 to 134,529)	10,534(8,989 to 11,991)	48,532(44,310 to 53,080)	3,732(2,987 to 4,466)	12,946(11,336 to 14,669)
Percent change, %	168.2		111.4		141.5		331.1		360.7		246.9	
ASMR (95% UI)	5.34(5.07 to 5.52)	6.62(6.11 to 7.06)	8.52(8.12 to 8.72)	9.64(8.83 to 10.16)	6.37(6.09 to 6.61)	7.84(7.17 to 8.40)	2.87(2.68 to 3.06)	5.03(4.48 to 5.63)	1.91(1.62 to 2.18)	3.75(3.44 to 4.09)	1.71(1.35 to 2.04)	2.72(2.38 to 3.09)
Percent change, %	24.0		13.1		23.1		75.3		96.3		59.1	
Net Drifft(%, per year)	0.59(0.54 to 0.65)		0.22(0.13 to 0.32)		0.45(0.36 to 0.53)		1.63(1.54 to 1.71)		2.17(2.10 to 2.24)		1.57(1.48 to 1.66)	
DALYs (95% UI)	4,647,207(4,465,440 to 4,812,129)	11,549,016(10,777,405 to 12,338,912)	1,891,864(1,832,587 to 1,922,820)	3,564,050(3,347,923 to 3,733,175)	1,618,722(1,552,786 to 1,680,981)	3,553,955(3272690 to 3819144)	753,881(697,543 to 811,889)	2,901,059(2,595,114 to 3,249,069)	280,954(240,632 to 321,228)	1,188,693(1,080,190 to 1,309,276)	100,183(80,547 to 120,048)	335,996(293,809 to 382,001)
Percent change, %	148.5		88.4		119.6		284.8		358.7		235.4	
ASDR (95% UI)	115.47(110.82 to 119.6)	139.61(130.18 to 149.14)	184.52(179 to 187.44)	199.56(188.72 to 208.45)	147.63(141.56 to 153.33)	174.39(160.45 to 187.43)	67.93(63.14 to 72.8)	112.46(100.62 to 125.99)	44.17(37.74 to 50.39)	84.23(76.65 to 92.46)	39.7(31.79 to 47.5)	61.39(53.86 to 69.73)
Percent change, %	20.9		8.2		18.1		65.6		90.7		54.6	
Net Drifft(%, per year)	0.59(0.54 to 0.64)		0.23(0.17 to 0.28)		0.44(0.36 to 0.52)		1.61(1.51 to 1.71)		2.16(2.09 to 2.23)		1.56(1.51 to 1.62)	

The percentage change of the 2019 value relative to the initial 1990 value

The net drift value of age-standardized rates from 1990 to 2019

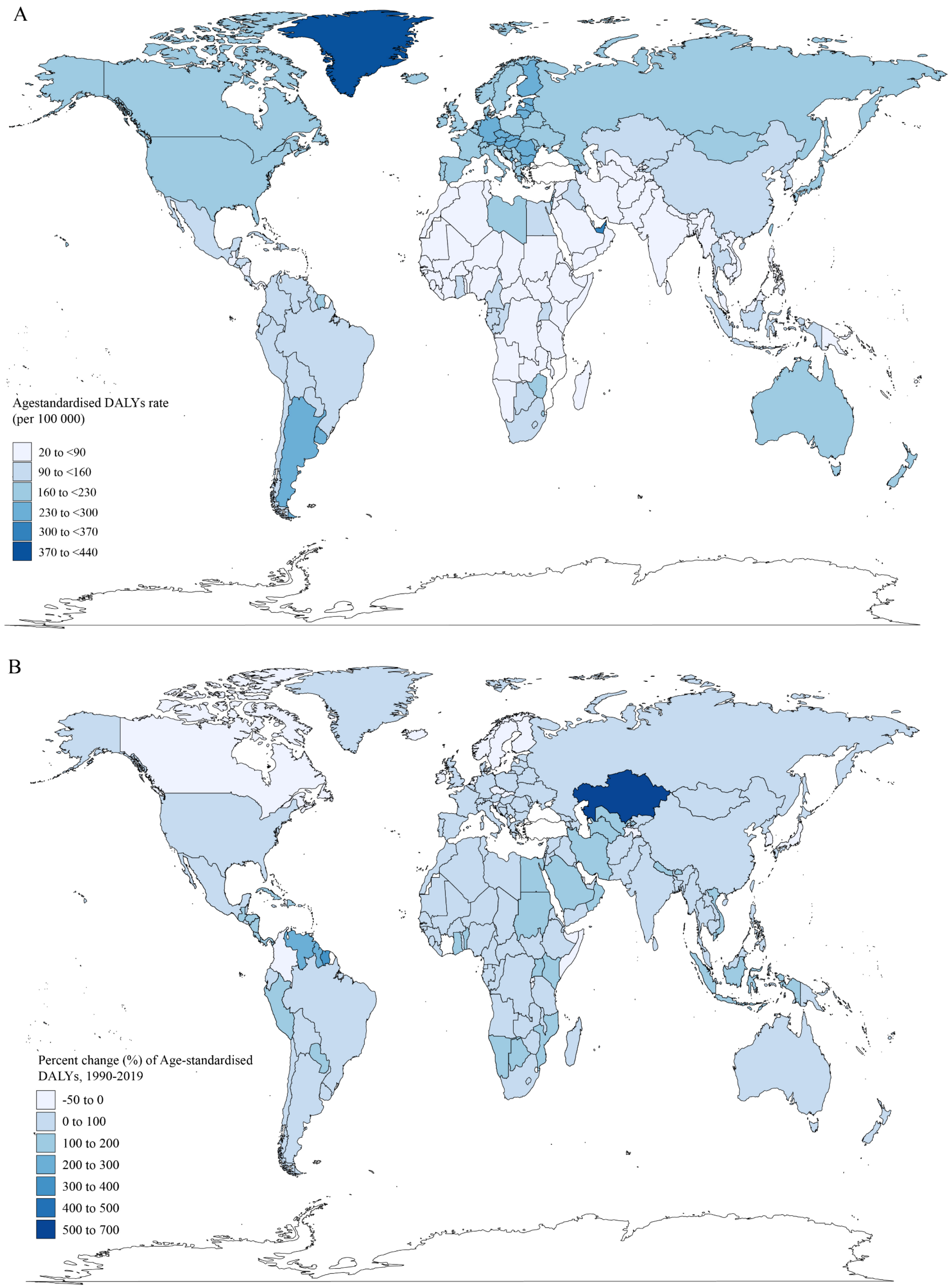

Fig. 2 (**A**) Geographical distribution of ASDR of pancreatic cancer in 2019. (**B**) The percentage change in ASDR of pancreatic cancer for 204 countries and territories from 1990 to 2019

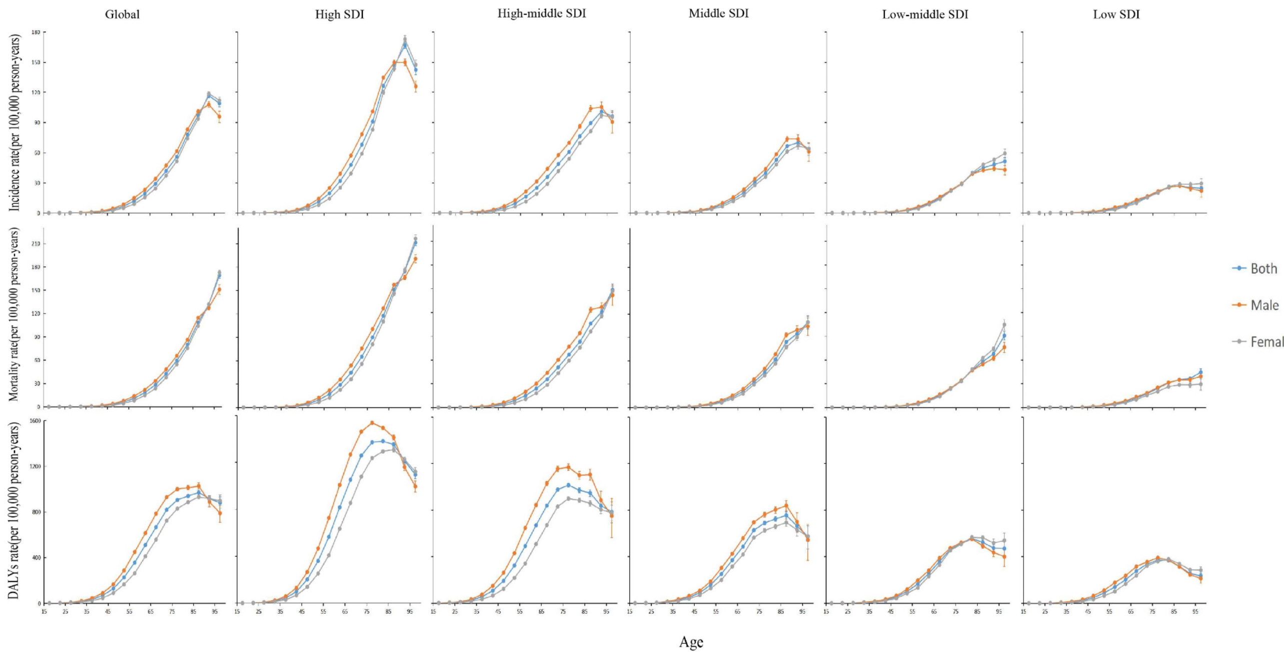

Fig. 3 Age effect analysis of incidence, death and DALY of pancreatic cancer in the world and countries and regions with different SDI from 1990 to 2019

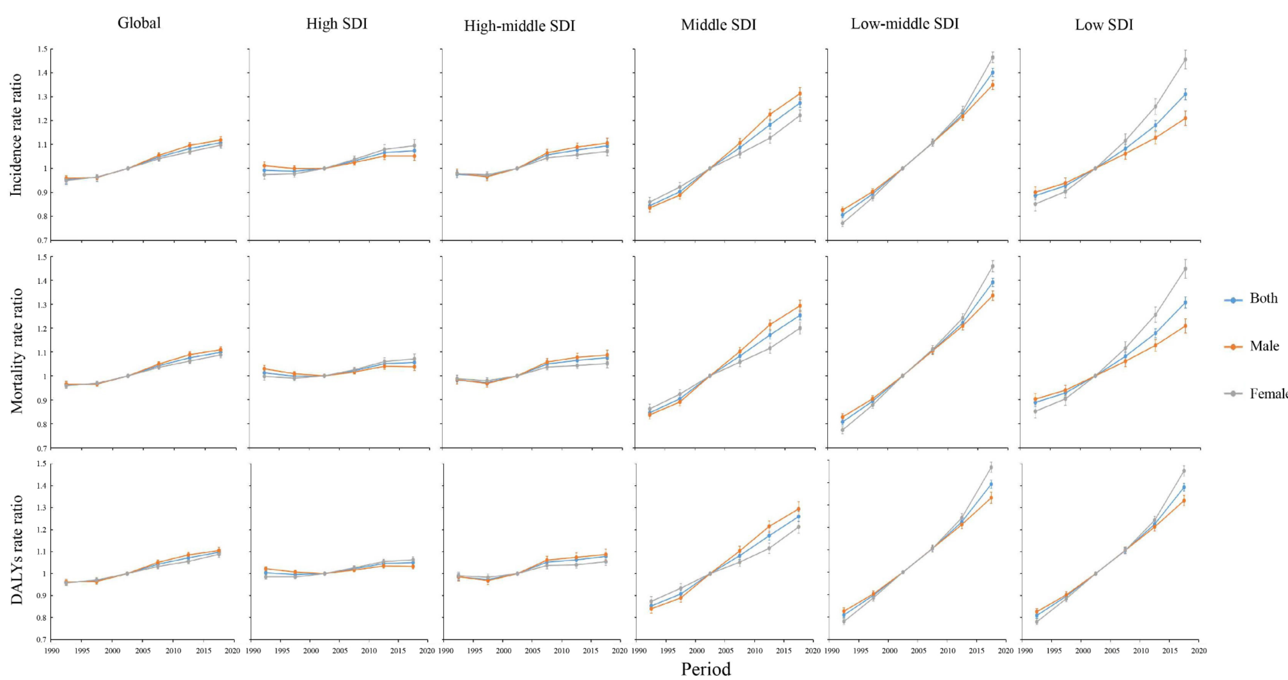

Fig. 4 Analysis of the period effect of incidence, death and, DALY of pancreatic cancer in the world and countries and regions with different SDI from 1990 to 2019

followed by a decline. In high SDI and middle-high SDI regions, the 75–79 age group exhibits the highest DALY rate, with a more pronounced increase compared to the global and other SDI regions.

Figure 4 presents the results of period effects, which show an increasing trend in the period risks of incidence, mortality, and DALY of pancreatic cancer globally over the period 1990–2019. For high SDI and high-middle SDI regions, the period effects have remained almost unchanged over the past two decades, indicating no significant increase in incidence, mortality, and DALY rates. However, during the period of 1990–2019, the period risks in middle SDI, low-middle SDI, and low SDI regions have increased significantly. with the difference being that in the middle SDI regions the period effect risk was higher for males compared with females in 2005–2019, whereas the opposite was true for the low-middle-SDI and low-SDI regions.

On a global scale, the risk of pancreatic cancer incidence for birth cohorts is increasing (Fig. 5). Like the period effect, the cohort effect was more pronounced in the middle SDI, low-middle SDI, and low SDI regions. The cohort effect of incidence for the whole population in low to middle SDI regions increased from 0.25 (0.18 to 0.37) in 1895 to 2.31 (1.92 to 4.37) in 2000, and the cohort effect of mortality and DALY followed a similar trend to incidence. In the middle SDI region, the cohort effect risk of onset for males in 2000 was 2.12 (1.56, 2.89), which was more than double that of females at 1.32 (0.89, 1.96), with mortality and DALY following a similar trend to onset.

Age-period-cohort effect of representative countries in different SDI regions

We analyzed representative countries in different SDI regions (Fig. 6), we found interesting patterns. The United States, representing a high SDI region, showed a rise and then decline in incidence and DALY rates with increasing age, reaching its peak in the age groups of 90–94 and 70–74, respectively. The period and cohort risks of incidence, death, and DALY remained relatively stable. Italy, as a representative country of high-middle SDI region, showed a decreasing trend in period and cohort effects, but had a higher risk of age effects than the other regions. China, as a representative country in the middle SDI region, had a similar age distribution of incidence, death, and DALY as the global pattern. with a more pronounced trend of elevation in the age group over 50 years, and significantly higher period and cohort effects. on the other hand, India, and Afghanistan, as countries represented by the low-middle SDI and low SDI regions, had lower incidence, mortality, and DALY rates compared to other SDI regions. However, the risk of period and cohort effects in these regions is significantly higher, with the increasing trend being more pronounced in India compared to Afghanistan.

Discussion

Our findings reveal that in 2019, pancreatic cancer claimed the lives of approximately 531,107 individuals globally. ASIR and ASMR rates of pancreatic cancer were found to be highest in Greenland and Monaco, while Ethiopia, Somalia, and Papua New Guinea had the lowest rates. These disparities in ASIR and ASMR rates across regions can likely be related to exposure factors, lifestyle, and socioeconomic level, and the lack of effective preventive measures [27, 28].

Our analysis shows that over the last three decades, the number of new cases, deaths, and DALY in 2019 has more than doubled compared to 1990, and even more than tripled in middle SDI and low-middle SDI regions. The significant rise in incidence and mortality rates of pancreatic cancer in most countries worldwide suggests a shift towards an aging population, particularly

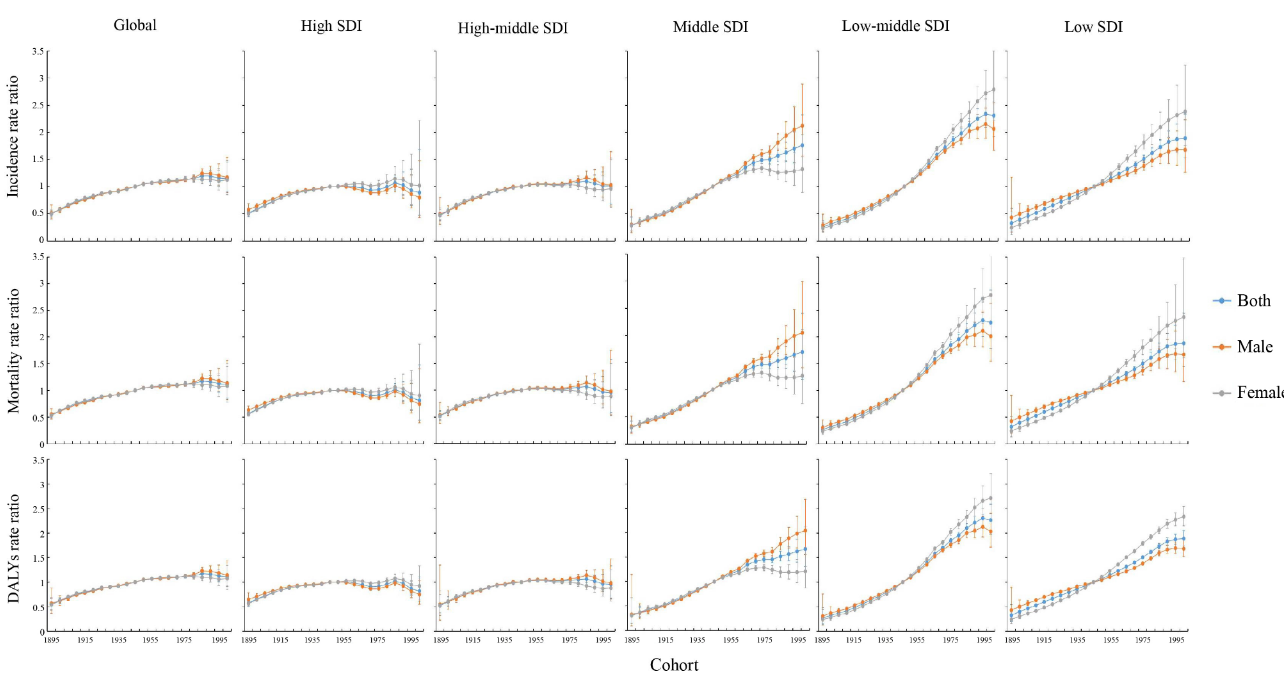

Fig. 5 Analysis of the cohort effect of incidence, death and, DALY of pancreatic cancer in the world and countries and regions with different SDI from 1990 to 2019

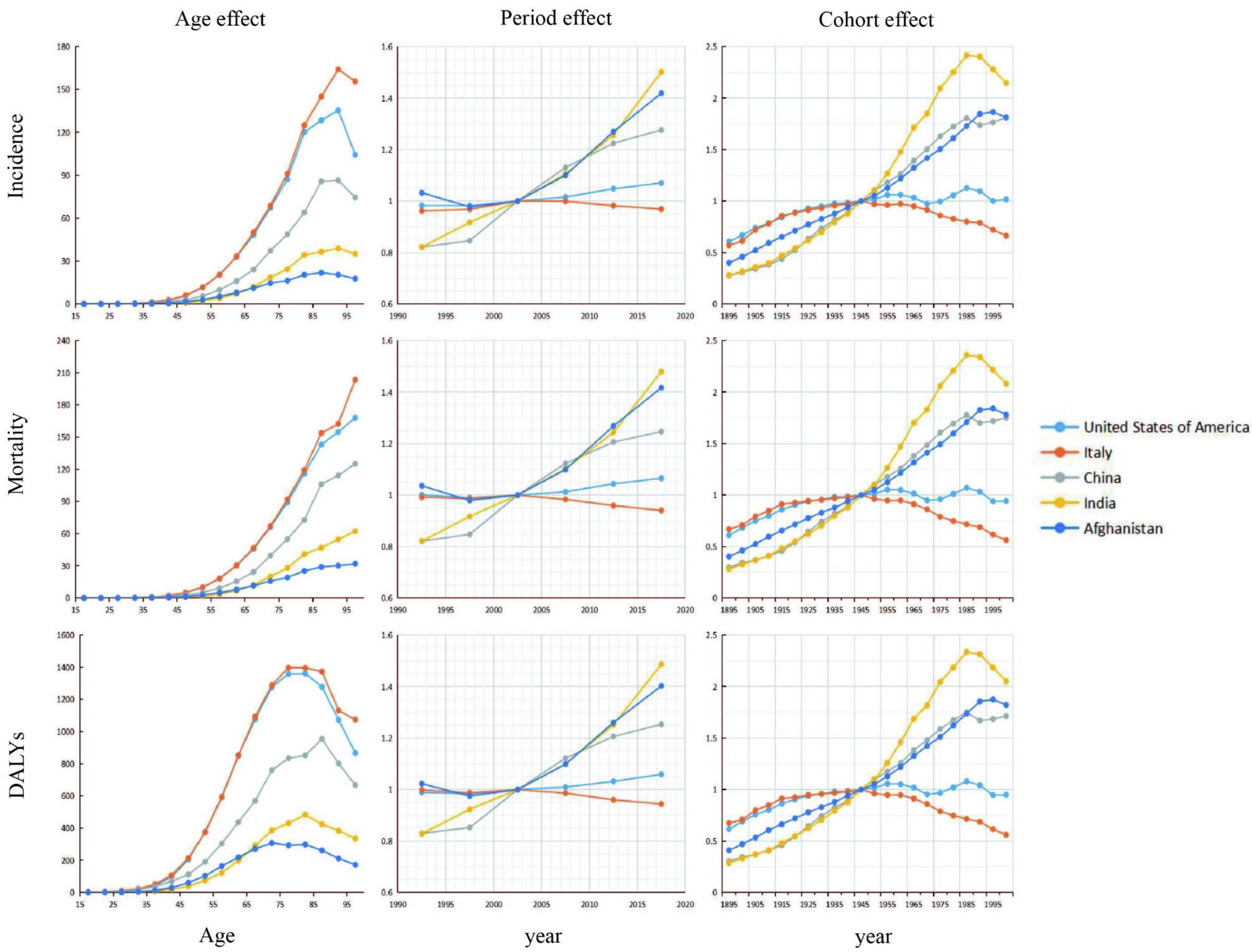

Fig. 6 Analysis of age-cohort-effect of representative countries in different SDI regions

in middle-low SDI countries. Environmental factors and lifestyle choices may also be contributing factors to the increased incidence and mortality rates of pancreatic cancer [29]. Tobacco is the most identified risk factor for pancreatic cancer. Our study results show that tobacco accounts for more than 50% of the population among the three main risk factors.

This study represents a pioneering effort in utilizing age-period-cohort models to examine the temporal trends in pancreatic cancer incidence, mortality, and DALY rates worldwide, with a particular focus on comparing different SDI regions. The findings derived from the age-period-cohort model demonstrate that age, period, and birth cohort have had a substantial impact on the incidence, mortality, and DALY rates of pancreatic cancer across genders and in diverse regions classified by SDI over the past three decades. On a global scale, the age effect indicates a consistent rise in pancreatic cancer incidence, mortality, and DALY rates with advancing age. This suggests that as the population ages, there is a notable increase in the number of elderly individuals diagnosed with pancreatic cancer, often at advanced stages of the disease. which will inevitably lead to an increase in the disease burden [30]. However, studies have shown that the association between pancreatic cancer risk factors is stronger in younger people, and that despite higher rates of pancreatic cancer incidence, mortality, and DALY in older adults, avoidance of risk factors at a younger age can largely reduce the incidence of pancreatic cancer [11, 31]. The period effect suggests that the risk of pancreatic cancer incidence, mortality and DALY increases over time, suggesting that the prevention and treatment of pancreatic cancer in healthcare facilities worldwide still needs to be improved, which is related to the fact that there is no effective means of screening for pancreatic cancer, and therefore understanding the etiology, identifying the relevant risk factors, and determining the at-risk population are key to both primary and secondary prevention [32, 33]. The birth cohort effect indicates that the rates of pancreatic cancer incidence, mortality, and DALY in specific populations born at a particular time are increasing, implying that lifestyle factors have a significant impact on pancreatic cancer. Among these factors, smoking remains one of the primary global causes of pancreatic cancer. Additionally, the increasing prevalence of diabetes and obesity contributes to the rising incidence rate of pancreatic cancer [34, 35].

In regions with high SDI, the rates of pancreatic cancer incidence, mortality, and DALY exhibit the most notable increase as individuals age. Statistics reveal that North America, Europe, and Australia are the regions with the highest incidence rates of pancreatic cancer. This can be attributed to a combination of factors, including the aging population and the higher prevalence of risk factors in these high SDI regions. Consequently, there is a heightened disease burden associated with pancreatic cancer in these areas [27]. The risks linked to period and cohort effects have remained relatively constant, highlighting the insufficient measures in place to mitigate the disease burden of pancreatic cancer. Nevertheless, control measures in high SDI regions are comparatively more effective. As a prominent high SDI country, the United States ranks pancreatic cancer as the third most common cause of cancer-related fatalities. Projections suggest that pancreatic cancer will ascend from the third to the second leading cause of cancer-related deaths in the US in the future [36, 37]. However, as a developed country, the United States has more advanced diagnostic and treatment measures, disease surveillance, and healthcare services for pancreatic cancer compared to lower SDI regions. Therefore, the risks associated with period and birth cohort effects are not significant [38, 39].

In the high-middle SDI area, the age, period and birth cohort effect of the incidence, mortality and DALY rates of pancreatic cancer are similar to the global level. Italy, as a representative country, the increasing trend in pancreatic cancer incidence is alarming [40]. About one-third of the cancer causes in the Italian population are independent risk factors of smoking and alcohol consumption [41]. Although the incidence and mortality rates of pancreatic cancer increased significantly, smoking and drinking, as controllable factors, can degrade the risk of incidence and mortality of pancreatic cancer to a certain extent through reasonable prevention and control measures, which also explains the reason why the risk of period and birth cohort shows a downward trend. In addition, Italy has set up a registry to manage high-risk groups with a family history of pancreatic cancer. Although there is no genetic test to identify family susceptibility in most high-risk groups, it is justifiable to offer screening for individuals at risk of developing pancreatic cancer [42, 43].

In the middle SDI region, the risk of period and birth cohort significantly increases. Among them, the disease burden of pancreatic cancer in China is experiencing a significant increase, and the mortality rate is basically equal to the incidence rate. The improvement of socio-economic status has also contributed to the rapid increase of the proportion of Chinese population in the global population. However, there are still socio-economic disparities between China and developed countries, the absence of a national screening plan for pancreatic cancer in China has resulted in delays in early detection and subsequent medical intervention. In China, the elderly and men have high incidence and mortality rates, which should be focused on [44, 45]. In addition, the Chinese people lack understanding of pancreatic cancer, and their investment in pancreatic cancer is relatively low compared with other cancers, leading to the backwardness of the diagnosis and treatment of pancreatic cancer in China. Therefore, over time, the risk of incidence, mortality, DALY rates gradually increase [46, 47]. Therefore, Chinese government should pay more attention to pancreatic cancer, strengthen the popularization of pancreatic cancer knowledge, make more people understand pancreatic cancer, and then reduce the disease burden of pancreatic cancer.

In regions with low-middle SDI and low SDI, the age, period, and cohort effect of female pancreatic cancer are higher than that of male with the increase of age and time. This may be due to the higher prevalence of obesity among women, which is similar to the pattern observed in China [48]. Additionally, in some regions, the smoking rate among women may be higher, increasing the risk of pancreatic cancer. In lower SDI regions, women may have less access to preventive medical check-ups and health education, leading to lower rates of early cancer detection. As a representative of low-middle SDI regions, pancreatic cancer has caused an increasing disease burden, mainly due to the use of tobacco. Smoking control has become one of the important preventive measures in low to middle SDI countries such as India [49].

There are several limitations to this study. First, the limitations of GBD model, due to the limited data of low- and middle-income countries, use the estimated values of neighboring regions instead. Secondly, only one third of the countries in the world report high-quality data. Therefore, the geographical coverage of data is limited, especially from countries with scarce resources. Thirdly, in the process of data collection, the differences in collection procedures, coding, sources of data processing and collection (hospital records/national registry) and data quality are still inevitable.

Conclusion

In conclusion, our research findings indicate a significant global increase in the incidence and mortality of pancreatic cancer, particularly in regions with a high SDI. Age, period, and birth cohort effects have a notable impact on the occurrence, death rate, and DALY associated with pancreatic cancer. The stability of period and birth cohort effects in high SDI and high-middle SDI regions underscores the influence of socio-economic factors on cancer prevention and control. Furthermore, as the population ages, the occurrence of pancreatic cancer rises. However, effective prevention and control measures can be implemented by reducing exposure to risk factors from an early age. Targeted strategies should be proposed to address specific risk factors for pancreatic cancer, such as reducing tobacco and alcohol consumption, managing weight and blood sugar levels, among others. In feasible scenarios, high-risk populations for pancreatic cancer, such as those with familial hereditary pancreatic cancer, should be registered and undergo regular screenings to alleviate the burden of severe diseases caused by pancreatic cancer.

Abbreviations

DALY	Disability adjusted life years
SDI	Socio-demographic index
GBD	Global Burden of Disease
AAPC	Average annual change percentage
ASIR	Age-standardized incidence rate
ASMR	Age-standardized mortality rate
ASDR	Age-standardized DALY rate
UI	Uncertainty interval

Supplementary Information

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Supplementary Material 1

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Author contributions
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Data availability
Data are available from the corresponding author on reasonable request.

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.

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The authors declare no competing interests.

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