

Research Article

Global and Regional Trends of the Incidence, Deaths, Prevalence, Disability-Adjusted Life Years, and Risk Factors for Diabetes, 1990-2021

Weilin Yang* , Wencai Jiang 

Department of Anesthesiology, Deyang People's Hospital, Deyang, China

Abstract

Purpose: We aim to analyze the global and regional trends of the total disease burden and risk factors of diabetes. **Methods:** This study was based on the Global Burden of Disease (GBD) Study 2021. The global and regional trends of incidence, deaths, prevalence, and disability-adjusted life years (DALYs) were assessed. Level 2 risk factors in the database were included. **Results:** In 2021, global diabetes incidence, deaths, prevalence, and DALYs were 24,442.18 thousand, 1,656.63 thousand, 525,654.11 thousand, and 78,938.59 thousand, respectively. From 1990 to 2021, global age-standardized rates increased significantly, with average annual percent changes (AAPCs) of +1.71% (incidence), +0.14% (deaths), +2.05% (prevalence), and +0.94% (DALYs). Middle and low-middle social-demographic index (SDI) regions accounted for over half of the global burden across all metrics. Low-middle SDI regions had the fastest growth in death (AAPC: +1.05%) and DALYs rates (AAPC: +1.32%), while high SDI and high-middle regions showed a mortality decline (AAPC: -1.48% and -0.24%). In recent years, global age-adjusted incidence, prevalence, and DALYs rates of diabetes maintained positive APCs, with low-middle SDI regions leading in growth, while high SDI regions saw declining mortality and accelerated incidence, and middle SDI regions sustained steady growth across key metrics. High fasting plasma glucose, high body mass index, and dietary risks were still the top three risk factors. **Conclusion:** The global diabetes burden has continued to rise over the past three decades. Low-middle SDI regions have the fastest growth in death and DALYs rates, while low SDI regions maintain persistently high mortality and DALYs. In recent years, low-middle and middle SDI regions still face sustained growth of age-adjusted deaths, highlighting the need for targeted interventions.

Keywords

Diabetes, Disease Burden, Risk Factors, SDI Regions, GBD 2021

1. Introduction

Diabetes is a chronic disease usually manifested as hyperglycemia. It occurs either when the pancreas does not produce enough insulin or when the body cannot effectively use the insulin it produces. Insulin is a hormone that regulates blood

glucose. Uncontrolled diabetes can lead to raised blood glucose and over time lead to serious complications, such as coronary heart disease, kidney dysfunction, impaired vision, diabetic polyneuritis, limb necrosis, and infections [1, 2]. The impact of poorly controlled diabetes is much more than this.

*Correspondence: Weilin Yang (ywl20100801@126.com)

Received: 26 April 2026; **Accepted:** 10 May 2026; **Published:** 2 June 2026



Cognitive function decline, cancers, nonalcoholic fatty liver disease, obstructive sleep apnea syndrome, and depression are newly determined to be related to diabetes [3]. Diabetes itself is associated with unusual glucose variability, which may cause hypoglycemic coma, diabetic ketoacidosis and hyperosmolar coma, and further sudden death [4]. In addition, blood glucose management is vital in perioperative periods, since there may be increased risk owing to gastroparesis, chronic heart disease, and/or kidney disease induced by diabetes [5]. The increased perioperative risks for diabetic patients include a higher incidence of vomiting and aspiration, cardiovascular events, abnormal drug metabolism, postoperative infections, and so on [5, 6].

According to the updated world health statistics report released by the World Health Organization (WHO), deaths from diabetes have risen from outside the top 10 in 2000 to the top 10 globally [7]. The International Diabetes Federation (IDF) estimated that the number of diabetes patients is over 537 million in 2021 [8], which is roughly in line with the Global Burden of Disease Study 2021 (GBD 2021) [9]. Worse still, the IDF estimation indicates that approximately 783 million (1/8) adults will be accompanied by diabetes by 2045 [10]. As a lifelong disease, the treatment of diabetes is expensive, let alone the cost of treating its complications. In the United States of America (USA), the estimated fee for diabetes in 2022 is 412.9 billion dollars, of which, 306.6 billion dollars is directly related to medical issues and 106.3 billion dollars for indirect expenditures (i.e., reduced productivity) [11]. Globally, the costs will be continuously increased to over 2 trillion dollars by 2030 [12].

The great influence of diabetes on both human health and economic burden calls for accurate data on diabetes burden to guide health policies and medical practice. Sun et al. [13] analyzed the diabetes burden from 1990 to 2019 and predicted that the burden would keep increasing. In this study, we will present the data of 1990, 2000, 2010, 2020, and 2021 to show the global and regional trends of diabetes burden. Meanwhile, we will also analyze the risk factors to help with prevention strategies for diabetes.

2. Materials and Methods

2.1. Data Source

The data of this study is based on the GBD 2021, the latest edition of the estimation of the global burden of disease [9]. The GBD study was initiated by the American Institute for Health Metrics and Evaluation (IHME) based at School of Medicine, University of Washington. Related data is freely accessible in the official database Global Health Data Exchange (GHDx). Since its inception, the GBD study has been well-recognized worldwide and derived lots of secondary studies on disease burden [14-16].

2.2. Data Extraction

In the GHDx database, we first checked the number of incidences, deaths, prevalence, and disability-adjusted life years (DALYs) of diabetes. One DALY represents the loss of the equivalent of one year of full health. The larger DALYs indicate a heavier disease burden. The IHME defined 8 level 2 risk factors for diabetes, including air pollution, dietary risks, high alcohol use, high body mass index (BMI), high fasting plasma glucose, low physical activity, non-optimal temperature, and tobacco. For the risk factor “high fasting plasma glucose”, the GBD study defines exposure as levels above the theoretical minimum risk exposure range (TMREL) of 4.8-5.4 mmol/L (86.4-97.2 mg/dL) [17]. Then the location included global, high social-demographic index (SDI), high-middle SDI, middle SDI, low-middle SDI, and low SDI. SDI, an indicator evaluating the national socio-economic development level, is comprehensively determined by fertility rate, residents’ income level, and educational degree. SDI level is closely connected with health outcomes [18]. It is calculated as the geometric mean of the indices for: 1) total fertility rate under age 25, 2) mean education for persons aged 15 and older, and 3) lag-distributed income per capita. This index is classified into five categories Low, Low-middle, Middle, High-middle, and High with SDI values between 0.000-0.455, 0.456-0.608, 0.609-0.689, 0.690-0.805, and 0.806-1.000, respectively. In the GBD study, all locations are ranked by their SDI value and grouped into five quintiles: low, low-middle, middle, high-middle, and high SDI regions. The data for diabetes burden and risk factors from 1990 to 2021 were finally exported.

2.3. Data Processing and Statistical Analysis

Data were presented as estimated values with 95% uncertainty intervals (UIs), which are generated by the IHME to account for uncertainties from sampling error, model specification, and non-representative data. Detailed methods for calculating UIs are described in the GBD protocol [19].

Joinpoint regression analysis was applied to further quantify and verify trends in age-adjusted rates of incidence, deaths, prevalence, and DALYs. This method identifies inflection points (joinpoints) in time series data, allowing the calculation of annual percent changes (APCs) for different time segments and overall average annual percent changes (AAPCs) for the entire study period (1990–2021).

Microsoft Office Excel 2021 was used for data storage and preliminary processing. Joinpoint Regression Program (Version 5.4.0) was employed for Joinpoint regression analysis, with statistical significance set at $P < 0.05$.

2.4. Patient and Public Involvement

Patients or the public were not involved in the design, or

conduct, or reporting, or dissemination plans of our research.

3. Results

3.1. The Trends of Incidence

In 2021, the global number of newly diagnosed diabetes cases was estimated at 24,442.18 thousand [95% UI:

22,643.51–26,301.70 thousand], approximately three times that of 1990 (7,780.27 thousand) (Table 1). By region, the incidence numbers in high SDI, high-middle SDI, middle SDI, low-middle SDI, and low SDI regions in 2021 were 5,048.07 thousand [95% UI: 4,717.30–5,376.85 thousand], 4,210.64 thousand [95% UI: 3,852.19–4,588.61 thousand], 7,906.20 thousand [95% UI: 9,259.52–8,592.13 thousand], 5,341.31 thousand [95% UI: 4,937.19–5,762.43 thousand], and 1,911.02 thousand [95% UI: 1,773.05–2,070.41 thousand], respectively (Table 1).

Table 1. Populations of the incidence, deaths, prevalence and DALYs of different SDI regions. The data are shown as number [95% UI] (percentage). The unit of data is thousand. SDI, socio-demographic index; DALYs, disability-adjusted life years.

Variables	1990	2000	2010	2020	2021
Incidence					
Global	7780.27 [7193.59, 8397.76] (100)	11481.12 [10697.30, 12328.88] (100)	16633.86 [15580.17, 17832.33] (100)	23615.01 [21925.99, 25385.07] (100)	24442.18 [22643.51, 26301.70] (100)
High SDI	1699.96 [1574.18, 1830.15] (21.85)	2452.72 [2293.14, 2609.12] (21.36)	3493.26 [3287.31, 3703.47] (21.00)	4872.66 [4553.11, 5211.88] (20.63)	5048.07 [4717.30, 5376.85] (20.65)
High-middle SDI	1709.13 [1568.46, 1861.88] (21.97)	2483.63 [2291.03, 2681.23] (21.63)	3302.59 [3072.86, 3570.13] (19.85)	4143.67 [3795.42, 4506.17] (17.55)	4210.64 [3852.19, 4588.61] (17.23)
Middle SDI	2542.98 [2335.95, 2767.68] (32.68)	3745.17 [3462.98, 4051.11] (32.62)	5435.80 [5064.67, 5869.26] (32.68)	7656.08 [7041.07, 8301.39] (34.42)	7906.20 [7259.52, 8592.13] (32.35)
Low-middle SDI	1338.04 [1236.04, 1446.09] (17.20)	2065.58 [1918.48, 2229.07] (18.00)	3265.82 [3035.66, 3515.43] (19.63)	5106.94 [4744.26, 5502.58] (21.63)	5341.31 [4937.19, 5762.43] (21.85)
Low SDI	480.50 [444.84, 520.36] (6.18)	720.89 [670.37, 777.10] (6.28)	1118.16 [1044.83, 1200.86] (6.72)	1811.47 [1680.98, 1952.43] (7.67)	1911.02 [1773.05, 2070.41] (7.82)
Deaths					
Global	672.02 [635.44, 705.31] (100)	897.30 [852.93, 930.51] (100)	1173.81 [1113.02, 1216.08] (100)	1625.60 [1513.45, 1722.40] (100)	1656.63 [1537.70, 1759.55] (100)
High SDI	148.64 [138.38, 153.98] (22.12)	183.19 [168.48, 190.85] (20.42)	187.82 [168.25, 197.67] (16.00)	204.80 [182.75, 216.49] (12.60)	208.89 [185.86, 221.17] (12.61)
High-middle SDI	116.41 [109.33, 121.84] (17.32)	148.03 [139.58, 155.31] (16.50)	175.52 [162.96, 183.74] (14.95)	236.99 [215.07, 253.03] (14.58)	240.41 [217.59, 259.73] (14.51)
Middle SDI	191.25 [178.57, 201.95] (28.46)	272.98 [261.02, 283.93] (30.42)	392.27 [374.52, 406.04] (33.42)	575.55 [537.25, 608.77] (35.41)	590.77 [547.72, 628.55] (35.66)
Low-middle SDI	141.74 [129.97, 153.16] (21.09)	200.02 [186.10, 210.89] (22.29)	300.86 [284.08, 315.95] (25.63)	445.76 [412.55, 483.26] (27.42)	451.88 [413.45, 490.41] (27.28)
Low SDI	72.88 [65.85, 81.43] (10.84)	91.80 [84.03, 101.03] (10.23)	115.75 [106.37, 126.20] (9.86)	160.51 [143.50, 180.25] (9.87)	162.68 [146.06, 181.92] (9.82)
Prevalence					
Global	139107.88 [128055.50, 150839.98] (100)	216767.91 [201463.50, 234138.19] (100)	326141.62 [305983.08, 349505.52] (100)	503786.75 [470111.72, 540475.25] (100)	525654.11 [490915.91, 565380.79] (100)
High SDI	33473.76 [31106.89, 36120.68] (24.06)	49948.11 [47045.93, 53057.96] (23.04)	75053.27 [71275.48, 79506.79] (23.01)	115796.87 [109276.75, 123010.68] (22.99)	121029.22 [114175.11, 128605.62] (23.02)

Variables	1990	2000	2010	2020	2021
Incidence					
High-middle SDI	32227.53 [29615.50, 35006.50] (23.17)	50500.12 [46906.65, 54454.32] (23.30)	70396.43 [65907.93, 75562.51] (21.58)	100626.92 [93550.38, 108447.72] (19.97)	103936.65 [96642.84, 112109.21] (19.77)
Middle SDI	43667.19 [39910.82, 47682.82] (31.39)	69187.32 [63991.68, 75282.78] (31.92)	103684.39 [96552.39, 111646.42] (31.79)	159925.89 [148157.96, 172890.23] (31.74)	166520.96 [154703.16, 180874.32] (31.68)
Low-middle SDI	22120.87 [20255.08, 24074.99] (15.90)	35263.23 [32477.45, 38160.99] (16.27)	57972.52 [53617.69, 62456.47] (17.78)	95876.81 [88852.48, 103382.86] (19.03)	100809.77 [93152.09, 108662.72] (19.18)
Low SDI	7452.51 [6848.39, 8099.47] (5.36)	11633.16 [10722.75, 12584.55] (5.37)	18695.00 [17319.78, 20123.85] (5.73)	31080.41 [28744.83, 33513.17] (6.17)	32859.09 [30377.07, 35429.67] (6.25)
DALYs					
Global	27504.00 [24299.17, 31667.09] (100)	38459.86 [33635.72, 44971.51] (100)	52741.09 [45297.41, 62140.61] (100)	76517.02 [64861.42, 92223.99] (100)	78938.59 [66772.20, 94495.83] (100)

Figure 1A shows the dynamic changes of global and regional age-adjusted rate of diabetes incidence. All SDI regions saw a sustained rise in age-standardized diabetes incidence be-

tween 1990 and 2021. The high SDI region exhibited the fastest growth, widening its gap with other regions over time; the low SDI region rose more gradually, while global incidence tracked the upward trend driven by high SDI growth.

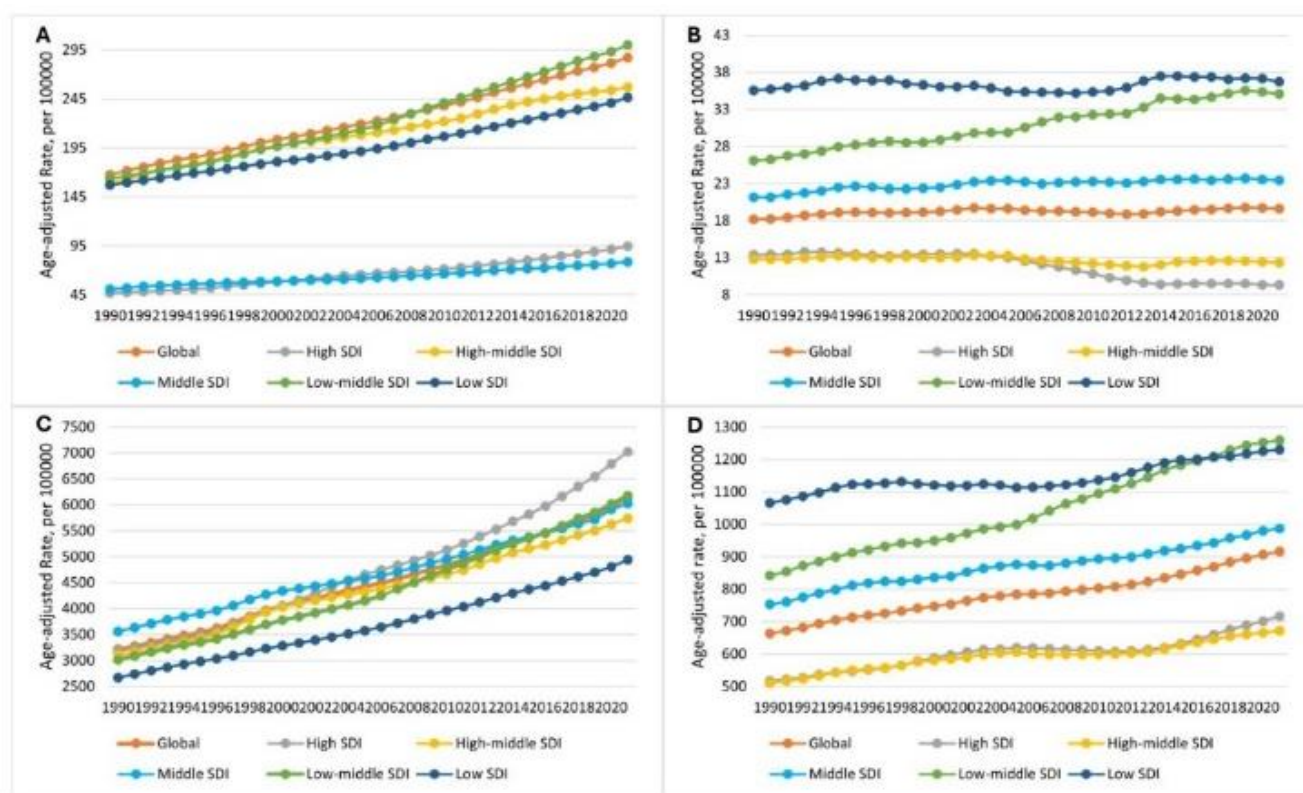


Figure 1. Global and regional dynamics of age-adjusted rates in incidence (A), deaths (B), prevalence (C), and DALYs (D).

Globally, the age-adjusted rate rose steadily with an AAPC of +1.71% over 31 years, maintaining growth in recent years

(2014–2021: APC +1.61%) (Table 2, Table 3). Regionally, high SDI regions had the fastest overall growth (AAPC

+2.31%), with robust recent growth (2016–2021: APC +2.68%), followed by low-middle SDI regions (APCC: +2.02%) (Table 2, Table 3). Middle SDI regions kept steady growth (2019–2021: APC +1.71%), while high-middle SDI

regions had the lowest recent growth (2015–2021: APC +0.95%) due to sustained deceleration (Table 3). Low SDI regions showed consistent acceleration, with their latest growth (2019–2021: APC +1.93%) reaching a regional high (Table 3).

Table 2. Average annual percent changes (AAPCs) of age-adjusted rate of the incidence, deaths, prevalence, and DALYs of diabetes from 1990 to 2021.

Variables	AAPC	95% CI
Incidence		
Global	1.71%	1.69-1.73%
High SDI	2.31%	2.24-2.37%
High-middle SDI	1.50%	1.44-1.56%
Middle SDI	1.35%	1.31-1.39%
Low-middle SDI	2.02%	1.99-2.06%
Low SDI	1.42%	1.40-1.45%
Deaths		
Global	0.14%	0.08-0.21%
High SDI	-1.48%	-1.71--1.24%
High-middle SDI	-0.24%	-0.35--0.13%
Middle SDI	0.30%	0.24-0.36%
Low-middle SDI	1.05%	0.99-1.11%
Low SDI	0.06%	-0.03-0.15%
Prevalence		
Global	2.05%	2.01-2.08%
High SDI	2.56%	2.51-2.62%
High-middle SDI	1.95%	1.87-2.04%
Middle SDI	1.61%	1.60-1.65%
Low-middle SDI	2.35%	2.31-2.38%
Low SDI	1.94%	1.93-1.96%
DALYs		
Global	0.94%	0.90-0.99%
High SDI	0.87%	0.77-0.97%
High-middle SDI	0.76%	0.68-0.84%
Middle SDI	0.77%	0.73-0.81%
Low-middle SDI	1.32%	1.27-1.36%
Low SDI	0.35%	0.29-0.42%

Table 3. Annual percent changes (APCs) of age-adjusted rate of the incidence of diabetes from 1990 to 2021.

Variables	Lower endpoint	Upper endpoint	APC	95% CI	P value
Global	1990	1993	2.28%	2.20-2.37%	<0.001
	1993	1996	1.61%	1.54-1.68%	<0.001
	1996	1999	2.09%	2.02-2.15%	<0.001
	1999	2006	1.50%	1.46-1.53%	<0.001
	2006	2011	1.72%	1.62-1.78%	<0.001
	2011	2014	1.94%	1.83-1.99%	<0.001
	2014	2021	1.61%	1.57-1.63%	<0.001
High SDI	1990	1996	1.79%	1.73-1.85%	<0.001
	1996	1999	3.34%	3.17-3.44%	<0.001
	1999	2004	2.65%	2.55-2.71%	<0.001
	2004	2011	1.76%	1.69-1.81%	<0.001
	2011	2016	2.42%	2.06-2.49%	<0.001
	2016	2021	2.68%	2.59-2.87%	<0.001
High-middle SDI	1990	1993	2.83%	2.71-2.96%	<0.001
	1993	1996	1.77%	1.65-1.88%	<0.001
	1996	1999	2.30%	2.20-2.41%	<0.001
	1999	2006	1.15%	1.05-1.20%	<0.001
	2006	2010	1.29%	1.21-1.90%	<0.001
	2010	2015	1.83%	0.92-1.93%	<0.001
	2015	2021	0.95%	0.88-1.05%	<0.001
Middle SDI	1990	1993	2.59%	2.49-2.70%	<0.001
	1993	1998	1.18%	1.12-1.26%	<0.001
	1998	2005	0.95%	0.90-0.99%	<0.001
	2005	2014	1.61%	1.58-1.64%	<0.001
	2014	2019	1.31%	1.17-1.38%	<0.001
	2019	2021	1.71%	1.48-1.85%	<0.001
Low-middle SDI	1990	1996	1.65%	1.58-1.69%	<0.001
	1996	1999	2.33%	1.75-2.41%	<0.001
	1999	2003	1.63%	1.53-2.23%	<0.001
	2003	2006	1.82%	1.71-2.68%	<0.001
	2006	2009	2.65%	2.20-2.73%	<0.001
	2009	2014	2.19%	1.91-2.24%	<0.001
	2014	2021	1.90%	1.86-1.95%	<0.001
Low SDI	1990	1993	1.54%	1.43-1.70%	<0.001
	1993	1999	1.37%	1.13-1.41%	<0.001
	1999	2005	1.14%	1.08-1.55%	<0.001
	2005	2016	1.59%	1.57-1.64%	<0.001

Variables	Lower endpoint	Upper endpoint	APC	95% CI	P value
	2016	2019	1.41%	1.34-1.51%	<0.001
	2019	2021	1.93%	1.76-2.06%	<0.001

3.2. The Trends of Deaths

Global deaths attributable to diabetes increased from 672.02 thousand [95% UI: 635.44–705.31 thousand] in 1990 to 1,656.63 thousand [95% UI: 1,537.70–1,759.55 thousand] in 2021 (Table 1). Regionally, deaths in high SDI, high-middle SDI, middle SDI, low-middle SDI, and low SDI regions rose from 148.64 thousand, 116.41 thousand, 191.25 thousand, 141.74 thousand, and 72.88 thousand in 1990 to 208.89 thousand, 240.41 thousand, 590.77 thousand, 451.88 thousand, and 162.68 thousand in 2021, respectively (Table 1).

Figure 1B exhibits the dynamic changes of global and regional age-adjusted rate of deaths caused by diabetes. Trends diverged sharply across regions: the high SDI regions saw a steady decline in age-standardized mortality, while the low SDI regions maintained a high, slowly rising death rate. Middle and low-middle SDI regions showed mild upward trends, and global mortality remained relatively stable, balanced by high SDI's decline and other regions' increases.

Globally, diabetes-related age-adjusted death rates showed

an overall upward trend but with a notable recent shift: after accelerating from 2012–2019 (APC: +0.68%), rates slightly declined from 2019–2021 (APC: -0.53%) (Table 4). Regionally, disparities widened in recent years. High SDI regions maintained a long-term downward trend (AAPC: -1.48%), with a further slight decline in 2017–2021 (APC: -0.65%) after a sharp drop in 2005–2014 (APC: -3.65%) (Table 2, Table 4). Low-middle SDI regions had the fastest growth from 1990 to 2021 (AAPC: +1.05%), with persistent increases in 2014–2021 (APC: +0.55%) following rapid growth in 2011–2014 (APC: +2.08%) (Table 2, Table 4). Middle SDI regions showed steady growth (2007–2021 APC: +0.19%) with no recent deceleration (Table 4). High-middle SDI regions fluctuated, declining in 2016–2021 (APC: -0.42%) after a short 2013–2016 acceleration (Table 4). Low SDI regions also declined in 2014–2021 (APC: -0.23%) following a 2011–2014 surge (Table 4). Recent trends (2014–2021) highlight a clear divide: high, high-middle, and low SDI regions saw slowing or declining death rates, while low-middle and middle SDI regions continued to face rising mortality.

Table 4. Annual percent changes (APCs) of age-adjusted rate of the deaths of diabetes from 1990 to 2021.

Variables	Lower endpoint	Upper endpoint	APC	95% CI	P value
Global	1990	1995	1.08%	0.92-1.25%	<0.001
	1995	2000	-0.01%	-0.31-0.13%	0.738
	2000	2003	1.10%	0.74-1.25%	<0.001
	2003	2012	-0.48%	-0.55--0.43%	<0.001
	2012	2019	0.68%	0.61-0.85%	0.002
	2019	2021	-0.53%	-1.06-0.00%	0.051
High SDI	1990	1994	0.75%	0.30-1.20%	0.003
	1994	1998	-0.93%	-1.65--0.21%	0.016
	1998	2002	0.68%	-0.07-1.44%	0.070
	2002	2005	-1.46%	-3.02-0.13%	0.069
	2005	2014	-3.65%	-3.83--3.46%	<0.001
	2014	2017	0.88%	-0.89-2.68%	0.303
High-middle SDI	1990	1995	0.69%	0.44-1.03%	0.004
	1995	2001	-0.21%	-0.66--0.03%	0.035
	2001	2004	1.02%	0.47-1.32%	0.025

Variables	Lower endpoint	Upper endpoint	APC	95% CI	P value
Middle SDI	2004	2007	-1.94%	-2.23--1.45%	0.027
	2007	2013	-1.15%	-1.32--0.71%	0.022
	2013	2016	2.37%	1.67-2.71%	0.018
	2016	2021	-0.42%	-0.82--0.14%	0.014
	1990	1996	1.24%	0.99-1.57%	0.002
	1996	2000	-0.44%	-1.03--0.02%	0.043
	2000	2004	1.39%	1.00-1.96%	0.017
Low-middle SDI	2004	2007	-0.58%	-0.86-0.03%	0.064
	2007	2021	0.19%	0.11-0.37%	0.015
	1990	1995	1.44%	0.97-2.60%	0.004
	1995	2005	0.71%	-0.08-0.88%	0.064
	2005	2008	2.22%	1.16-2.67%	0.007
	2008	2011	0.16%	-0.33-1.27%	0.416
	2011	2014	2.08%	1.15-2.58%	0.021
Low SDI	2014	2021	0.55%	0.11-0.78%	0.032
	1990	1995	0.97%	0.66-1.28%	0.002
	1995	2008	-0.42%	-0.59--0.24%	0.042
	2008	2011	0.25%	-0.43-1.42%	0.363
	2011	2014	1.94%	0.08-2.23%	0.048
	2014	2021	-0.23%	-0.41--0.09%	0.025

3.3. The Trends of Prevalence

In 2021, the global prevalence of diabetes reached 525,654.11 thousand [95% UI: 490,915.91–565,380.79 thousand], an increase of over 38 million, 30 million, and 19 million compared to 1990, 2000, and 2010, respectively (Table 1). Regionally, 2021 prevalence in middle SDI, high SDI, low-middle SDI, high-middle SDI, and low SDI regions was 166,520.96 thousand, 121,029.22 thousand, 100,809.77 thousand, 103,936.65 thousand, and 32,859.09 thousand, representing increases of over 12 million, 8 million, 7 million, 7 million, and 2 million since 1990, respectively (Table 1).

Figure 1C illustrates the temporal dynamics of age-adjusted diabetes prevalence rates at both global and regional levels. Age-standardized diabetes prevalence rose rapidly across all SDI regions from 1990 to 2021. The high SDI regions had the most dramatic growth, with its prevalence far outpacing other regions by 2021; the low SDI regions grew slowest but steadily, and global prevalence surged in line with high SDI's expansion.

The results of AAPC and APC according to Joinpoint regression were the same in terms of prevalence. Globally, the

age-adjusted diabetes prevalence rate rose steadily from 1990 to 2021, with an AAPC of +2.05%, showing no sign of deceleration in recent years (Table 2). Regionally, high SDI regions had the fastest long-term growth (AAPC: +2.56%), followed by low-middle SDI regions (AAPC: +2.35%) (Table 2). Notably, all regions maintained stable upward trends in recent decades, aligning with the global acceleration in prevalence growth observed since 2010 (Table 2).

3.4. The trends of DALYs

Diabetes-related DALYs continued to rise across all regions from 1990 to 2021. Middle SDI and low-middle SDI regions showed increasing proportional contributions, rising from 30.58% and 20.36% in 1990 to 34.20% and 24.04% in 2021, respectively (Table 1). In contrast, the proportions of high SDI, high-middle SDI, and low SDI regions declined (Table 1).

The dynamic shifts in global and regional age-adjusted rates of DALYs attributed to diabetes are presented in Figure 1D. The low SDI region maintained the highest age-standardized DALYs rate, which rose consistently; the low-middle SDI region accelerated its growth, nearing the low SDI level by 2021.

In contrast, the high SDI region saw a sustained decline in DALYs, and global DALYs rose mildly—driven by low/low-middle SDI growth, offset partly by high SDI's reduction.

Globally, diabetes-related age-adjusted DALYs rates rose steadily with an average annual percent change (AAPC) of 0.94% over 31 years, accelerating from 2012–2021 (APC: +1.37%) after slowing in 2003–2012 (APC: +0.57%) (Table 2, Table 5). Regionally, low-middle SDI regions drove the global rise with the highest AAPC (+1.32%), maintaining robust growth in 2014–2021 (APC: +1.17%) (Table 2, Table 5). High SDI regions saw a notable recent acceleration (2014–

2021: APC: +2.14%) following a slight decline (2005–2011: APC: -0.36%) (Table 5). Middle SDI regions had steady growth (2013–2021: APC: +1.07%), while high-middle SDI regions rebounded (2011–2021: APC: +1.26%) after a period of stagnation (Table 5). Low SDI regions showed modest recent growth (2014–2021: APC: +0.46%) following earlier fluctuations (Table 5). Notably, recent trends (2014–2021) highlight that low-middle, middle, and high SDI regions all experienced accelerated DALY growth, underscoring widening regional disparities in diabetes burden.

Table 5. Annual percent changes (APCs) of age-adjusted rate of the DALYs of diabetes from 1990 to 2021.

Variables	Lower endpoint	Upper endpoint	APC	95% CI	P value
Global	1990	1994	1.57%	1.442-1.74%	<0.001
	1994	2003	1.02%	0.97-1.07%	<0.001
	2003	2012	0.57%	0.51-0.62%	<0.001
	2012	2021	1.37%	1.32-1.43%	<0.001
High SDI	1990	1994	1.24%	1.07-1.51%	<0.001
	1994	1997	0.86%	0.71-1.81%	<0.001
	1997	2002	1.77%	0.67-1.98%	<0.001
	2002	2005	0.69%	-0.42-0.98%	0.138
	2005	2011	-0.36%	-0.55-0.61%	0.098
	2011	2014	0.64%	0.25-2.09%	0.038
High-middle SDI	2014	2021	2.14%	2.01-2.32%	<0.001
	1990	1994	1.60%	1.27-1.93%	<0.001
	1994	2004	1.08%	0.98-1.18%	<0.001
	2004	2011	-0.19%	-0.39-0.01%	0.060
	2011	2021	1.26%	1.16-1.37%	<0.001
Middle SDI	1990	1995	1.58%	1.39-1.74%	<0.001
	1995	2001	0.57%	0.26-0.78%	0.001
	2001	2004	1.30%	0.62-1.46%	<0.001
	2004	2007	0.03%	-0.15-1.03%	0.513
	2007	2013	0.61%	0.33-0.94%	0.002
	2013	2021	1.07%	0.96-1.35%	<0.001
Low-middle SDI	1990	1995	1.64%	1.39-1.89%	<0.001
	1995	2004	0.88%	0.76-1.01%	<0.001
	2004	2014	1.68%	1.57-1.80%	<0.001
	2014	2021	1.17%	0.98-1.35%	<0.001
Low SDI	1990	1995	1.09%	0.96-1.23%	<0.001
	1995	1998	0.10%	-0.08-0.91%	0.267
	1998	2007	-0.12%	-0.28-0.50%	0.062

Variables	Lower endpoint	Upper endpoint	APC	95% CI	P value
	2007	2011	0.66%	0.23-1.11%	0.016
	2011	2014	1.33%	0.56-1.46%	<0.001
	2014	2021	0.46%	0.35-0.55%	0.002

3.5. The Trend of Risk Factors for Diabetes

Overall, high fasting plasma glucose, high body mass index (BMI), and dietary risks were the top three risk factors for diabetes (Figure 2). Minor regional variations in rankings were

observed for tobacco, air pollution, high alcohol use, and non-optimal temperature: for example, air pollution was the fourth leading risk factor in low SDI regions but fifth in high SDI regions, and tobacco ranked fifth in all regions except high SDI regions (Figure 2).

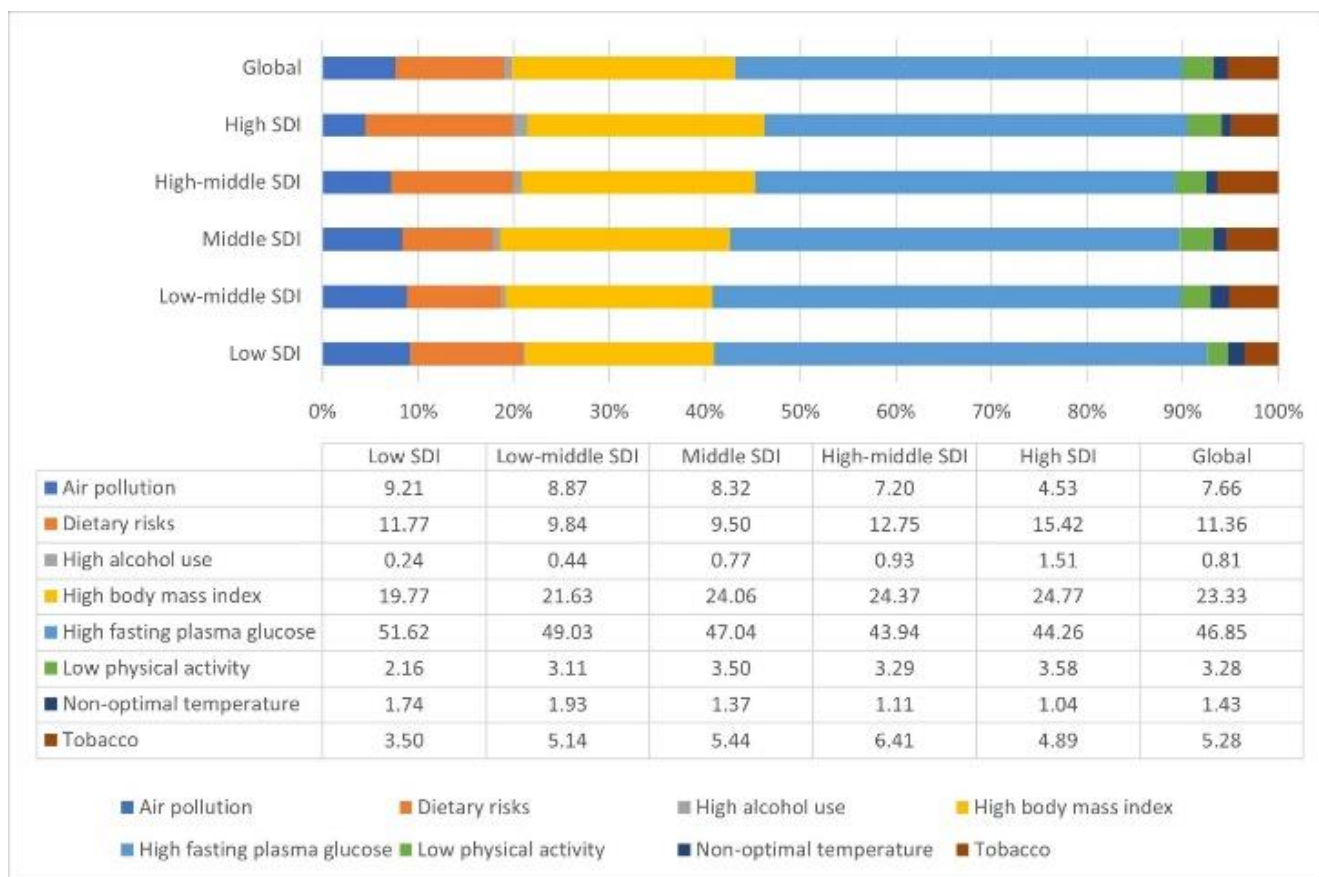


Figure 2. Proportions of diabetes attributable DALYs for different risk factors in 2021. DALYs, disability-adjusted life years. SDI, social-demographic index.

Air pollution: Global DALYs attributed to air pollution increased from 4,568.39 thousand [95% UI: 2,676.37–6,604.45 thousand] in 1990 to 12,904.49 thousand [95% UI: 7,501.41–19,485.25 thousand] in 2021 (Figure 3A). Middle SDI regions

had the largest increment (3,298.46 thousand), followed by low-middle SDI regions (2,460.51 thousand) and high-middle SDI regions (1,208.92 thousand) (Figure 3A).

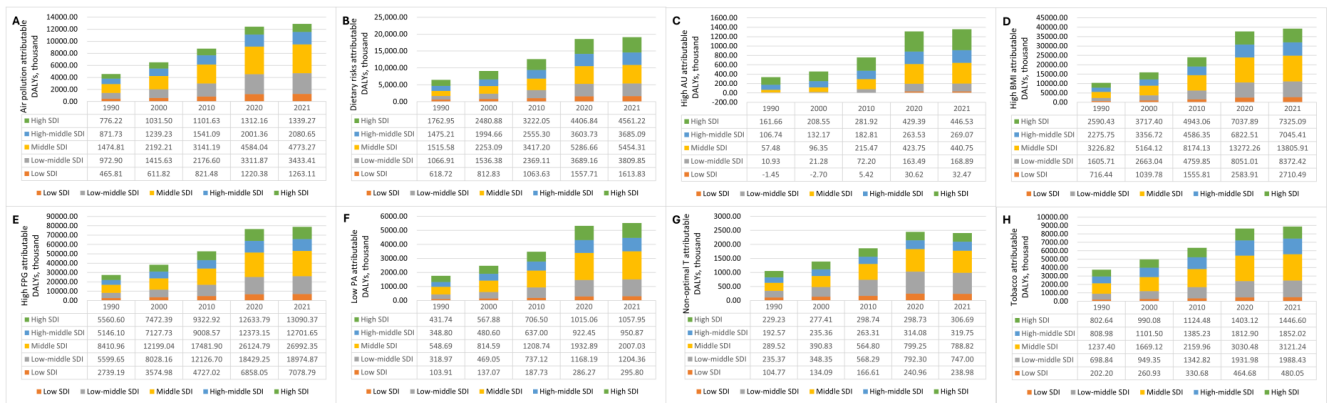


Figure 3. Trends of diabetes attributable DALYs induced by different risk factors. (A) Air pollution, (B) Dietary risks, (C) High alcohol use, (D) High BMI, (E) High fasting plasma glucose, (F) Low physical activity, (G) Non-optimal temperature, and (H) Tobacco use. DALYs, disability-adjusted life years. SDI, social-demographic index. AU, alcohol use. BMI, body mass index. FPG, fasting plasma glucose. PA, physical activity. T, temperature.

Dietary risks: Global dietary risk-related DALYs rose from 6,450.22 thousand [95% UI: 1,256.12–10,613.94 thousand] in 1990 to 19,146.81 thousand [95% UI: 4,147.24–31,937.62 thousand] in 2021 (Figure 3B). Middle SDI, high SDI, and high-middle SDI regions had substantially higher dietary risk-related DALYs than low SDI regions (Figure 3B).

High alcohol use: High SDI regions consistently had the highest DALYs from high alcohol use, while low SDI regions had the lowest (Figure 3C). However, by 2021, middle SDI regions had 440.75 thousand [95% UI: 138.48–893.00 thousand] alcohol-related DALYs, nearly matching high SDI regions (Figure 3C).

High body mass index (BMI): Global DALYs from high BMI increased from 10,434.89 thousand [95% UI: 4,873.20–15,314.31 thousand] in 1990 to 39,309.21 thousand [95% UI: 19,146.83–56,417.30 thousand] in 2021 (Figure 3D). Middle SDI regions had the largest increment (10,579.09 thousand), while low-middle SDI regions had the highest growth multiple (4.21x) (Figure 3D).

High fasting plasma glucose: As the leading risk factor, global DALYs from high fasting plasma glucose grew from 27,498.84 thousand [95% UI: 24,303.33–31,661.63 thousand] in 1990 to 78,929.11 thousand [95% UI: 66,789.96–94,530.02 thousand] in 2021 (Figure 3E). Middle SDI (2.21x growth) and low-middle SDI regions (2.39x growth) were most affected (Figure 3E).

Low physical activity: Global DALYs from low physical activity reached 5,523.05 thousand [95% UI: 2,407.13–8,638.53 thousand] in 2021, an increase of 3,767.97 thousand since 1990 (Figure 3F). Middle SDI and low-middle SDI regions led in absolute numbers, increments, and growth multiples (Figure 3F).

Non-optimal temperature: Global DALYs increased from 1,052.51 thousand [95% UI: 720.69–1,441.42 thousand] in 1990 to 2,447.06 thousand [95% UI: 1,473.93–3,727.66 thousand] in 2020, then slightly declined to 2,402.97 thousand [95% UI: 1,459.06–3,619.83 thousand] in 2021 (Figure 3G). High

SDI and high-middle SDI regions showed continued growth, while middle SDI, low-middle SDI, and low SDI regions had minor declines (Figure 3G).

Tobacco: Global tobacco-related DALYs reached 8,898.60 thousand [95% UI: 5,598.93–12,721.29 thousand] in 2021 (Figure 3H). Middle SDI regions had the largest proportional contribution across all ages; low-middle SDI regions surpassed high SDI regions in the 2000s and high-middle SDI regions in the 2010s (Figure 3H).

4. Discussion

This research outlines global and regional diabetes burden trends and key risk factors across SDI regions from 1990 to 2021. Globally, diabetes burden surged significantly: 2021 saw 24,442.18 thousand new cases, 1,656.63 thousand deaths, 525,654.11 thousand prevalent cases, and 78,938.59 thousand DALYs, with age-standardized rates rising steadily (AAPCs: +1.71% for incidence, +0.14% for deaths, +2.05% for prevalence, and +0.94% for DALYs). Regionally, middle and low-middle SDI regions accounted for over half of the global burden, with low-middle SDI regions showing the fastest growth in death (AAPC: +1.05%) and DALYs rates (AAPC: +1.32%), while high SDI regions had a mortality decline (AAPC: -1.48%). High fasting plasma glucose, high BMI, and dietary risks were the top three risk factors globally, with regional variations—such as air pollution ranking fourth in low SDI regions and tobacco-related DALYs in low-middle SDI regions surpassing high-middle and high SDI regions by the 2010s. These findings emphasize the need for targeted public health interventions, prioritizing middle and low-middle SDI regions and addressing modifiable risk factors to curb the rising diabetes burden.

Since diabetes is an incurable disease, the trend of diabetes burden is generally in line with life expectancy. The global population reached approximately 8.0 billion in 2022 and will slowly increase with a growth of < 1% per year in the next

decades [20]. Moreover, the average life expectancy of the world population reached 72.8 years in 2019 and is expected to reach 77.2 years in 2050 [20]. GBD 2021 Diabetes Collaborators [21] predicted diabetes burden in 2050. The results showed that the prevalence of diabetes would reach over 1.31 billion by 2050, and the prevalence rate in North Africa, the Middle East, Latin America, and the Caribbean would be at the leading level. In our study, the increase rates of prevalence in low SDI and low-middle SDI regions were at the top 2 levels and kept rising from 1990 to 2020, which is in accordance with the prediction [21]. The stark contrast in mortality trends—where the death rate declined in high-SDI regions but rose most sharply in low-middle SDI regions—highlights a critical inequity. It likely reflects disparities in access to quality healthcare, effective diabetes management programs, and perhaps later diagnosis in regions with rapidly growing incidence. Both domestic and international measures should be taken to give aid to the relatively undeveloped countries or regions.

In 2019, high fasting plasma glucose led to about 2864 DALYs per 100000 population in Europe, only 35.6% of which derived from diabetes [22]. This means populations with high fasting plasma glucose but not diagnosed with diabetes are risky to suffer other diseases and increase disease burden. As demonstrated in the GBD studies, the impacts of high fasting plasma glucose mainly manifested in vascular-related diseases, such as cardiovascular diseases [23], tumors [24], ischemic stroke [25], tuberculosis [26], chronic kidney disease [27], eye disorders [28] and neurocognitive disorders [29]. Our results showed that high fasting plasma glucose attributable DALYs grew more than 2 times from 1990 to 2021, and nearly 0.5 times from 2010 to 2021 globally. However, the rankings of the above-mentioned diseases did not rise from 2010 to 2021 [30]. This indirectly clued that the effects of prevention and protection measures for these diseases covered the impacts of high fasting plasma glucose.

The present study found that BMI caused 3.93 million diabetes attributable DALYs in 2021 worldwide. Fractions of middle SDI regions accounted for 35.12%, followed by low-middle SDI regions (21.30%), high SDI regions (18.63%), high-middle SDI regions (17.92%), and low SDI regions (6.89%). It should be noted that the contribution of low-middle SDI regions to diabetes attributable DALYs exceeded that of high-middle SDI and high SDI regions around 2010, indicating the fast growth of disease burden in low-middle SDI regions. The association between high BMI and type 2 diabetes has been well determined and recognized [1, 31]. In 2022, World Health Statistics 2024 published by WHO estimated that worldwide more than 1 billion obese population, and obesity prevalence among children or adults increased from 1990 to 2022 in all WHO regions, but the Americas Region and Eastern Mediterranean Region underwent the fastest growth of diabetes prevalence [7]. This report is a good explanation of the rapid rise of diabetes burden in low-middle SDI regions.

Dietary risks for diabetes include a diet low in whole grains, nuts and seeds, fiber, fruits, legumes, seafood omega-3 fatty acids, polyunsaturated fatty acids, or vegetables, and high in processed meat, red meat, trans fatty acids, sodium or sugar-sweetened beverages [17]. Poor dietary habits are the primary cause of childhood obesity and the number of bad eating habits is positively associated with metabolic syndrome development [32, 33]. Our results showed a severe burden of diet-induced diabetes, especially in the middle SDI (5.45 million DALYs), high SDI regions (4.56 million DALYs), and low-middle SDI regions (high growth speed in DALYs). Though the contribution of low physical activities to diabetes attributable DALYs is not as great as the 3 major risk factors according to this study, physical activity is effective in reducing premature mortality and preventing several chronic disorders [34]. Good living habits benefit not only diabetes but also holistic health.

The data reliability of the GBD study has been fully discussed by previous studies [21, 30]. There are some limitations in our study. First, we did not distinguish the types of diabetes. As reported in the previous study, the incidence, prevalence, deaths, and DALYs attributable to type 1 diabetes are about 2.92%, 5.16%, 5.30%, and 7.16% that of type 2 diabetes [13]. However, listing the 2 types separately is helpful to understand trends of disease burden and risk factors for type 1 diabetes. Second, we used only the absolute number of incident cases, prevalent cases, deaths, and DALYs. The consideration is that every single diabetic patient will lead to an increase in the consumption of medical, economic, and social resources. Thus, the increasing number may partly remind policymakers and scientific researchers that they should still pay attention to this disease. Last, we did not estimate special types of diabetes induced by drugs or other diseases and gestational diabetes because of the absence in the database.

5. Conclusion

The global diabetes burden has continued to rise over the past three decades, with age-standardized incidence, deaths, prevalence, and DALYs showing AAPCs of 1.71%, 0.14%, 2.05%, and 0.94% respectively. Middle and low-middle SDI regions account for over half of the global burden, with low-middle SDI regions having the fastest growth in deaths and DALYs rates, while low SDI regions maintain persistently high mortality and DALYs. In recent years, global age-adjusted incidence, prevalence, and DALYs rates have maintained positive APCs; high SDI regions show accelerated incidence but declining mortality, while low-middle and middle SDI regions face sustained burden growth. High fasting plasma glucose, high BMI, and dietary risks remain the top three risk factors, highlighting the need for targeted interventions prioritizing different SDI regions.

Abbreviations

GBD	Global Burden of Disease
DALYs	Disability-Adjusted Life Years
AAPCs	Average Annual Percent Changes
APCs	Annual Percent Changes
SDI	Social-Demographic Index
UI	Uncertainty Intervals
BMI	Body Mass Index
IHME	Institute for Health Metrics and Evaluation
GHDx	Global Health Data Exchange
IDF	International Diabetes Federation
SDGs	Sustainable Development Goals
YLDs	Years Lived with Disability
HALE	Healthy Life Expectancy

Author Contributions

Weilin Yang: Conceptualization, Data curation, Resources, Writing – original draft

Wencai Jiang: Data curation, Methodology, Writing – review & editing

Data Availability Statement

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

Conflicts of Interest

The authors have no conflict of interest to disclose.

References

- Ceriello, A. and F. Prattichizzo, Variability of risk factors and diabetes complications. *Cardiovasc Diabetol*, 2021. 20(1): p. 101. <https://doi.org/10.1186/s12933-021-01289-4>
- Kolarić, V., et al., CHRONIC COMPLICATIONS OF DIABETES AND QUALITY OF LIFE. *Acta Clin Croat*, 2022. 61(3): p. 520–527. <https://doi.org/10.20471/acc.2022.61.03.18>
- Tomic, D., J. E. Shaw, and D. J. Magliano, The burden and risks of emerging complications of diabetes mellitus. *Nat Rev Endocrinol*, 2022. 18(9): p. 525–539. <https://doi.org/10.1038/s41574-022-00690-7>
- Umpierrez, G. and M. Korytkowski, Diabetic emergencies - ketoacidosis, hyperglycaemic hyperosmolar state and hypoglycaemia. *Nat Rev Endocrinol*, 2016. 12(4): p. 222–32. <https://doi.org/10.1038/nrendo.2016.15>
- Cheisson, G., et al., Perioperative management of adult diabetic patients. Preoperative period. *Anaesth Crit Care Pain Med*, 2018. 37 Suppl 1: p. S9–s19. <https://doi.org/10.1016/j.accpm.2018.02.020>
- Berrón-Torres, S. I., et al., Centers for Disease Control and Prevention Guideline for the Prevention of Surgical Site Infection, 2017. *JAMA Surg*, 2017. 152(8): p. 784–791. <https://doi.org/10.1001/jamasurg.2017.0904>
- World health statistics 2024: monitoring health for the SDGs, Sustainable Development Goals. Geneva: World Health Organization; 2024. Licence: CC BY-NC-SA 3.0 IGO.
- International Diabetes Federation. IDF Diabetes Atlas, 10th edn. Brussels, Belgium: 2021. Available at: <https://www.diabetesatlas.org>
- Global Burden of Disease Collaborative Network. Global Burden of Disease Study 2021 (GBD 2021) Results. Seattle, United States: Institute for Health Metrics and Evaluation (IHME), 2022. Available from <https://vizhub.healthdata.org/gbd-results/>
- Sun, H., et al., IDF Diabetes Atlas: Global, regional and country-level diabetes prevalence estimates for 2021 and projections for 2045. *Diabetes Res Clin Pract*, 2022. 183: p. 109119. <https://doi.org/10.1016/j.diabres.2021.109119>
- Parker, E. D., et al., Economic Costs of Diabetes in the U.S. in 2022. *Diabetes Care*, 2024. 47(1): p. 26–43. <https://doi.org/10.2337/dci23-0085>
- Bommer, C., et al., Global Economic Burden of Diabetes in Adults: Projections From 2015 to 2030. *Diabetes Care*, 2018. 41(5): p. 963–970. <https://doi.org/10.2337/dc17-1962>
- Sun, J., et al., The Description and Prediction of Incidence, Prevalence, Mortality, Disability-Adjusted Life Years Cases, and Corresponding Age-Standardized Rates for Global Diabetes. *J Epidemiol Glob Health*, 2023. 13(3): p. 566–576. <https://doi.org/10.1007/s44197-023-00138-9>
- Murray, C. J. L., The Global Burden of Disease Study at 30 years. *Nat Med*, 2022. 28(10): p. 2019–2026. <https://doi.org/10.1038/s41591-022-01990-1>
- Li, Y., et al., Global, regional, and national disease burden estimates of acute lower respiratory infections due to respiratory syncytial virus in children younger than 5 years in 2019: a systematic analysis. *Lancet*, 2022. 399(10340): p. 2047–2064. [https://doi.org/10.1016/S0140-6736\(22\)00478-0](https://doi.org/10.1016/S0140-6736(22)00478-0)
- Ma, Q., et al., Temporal trend and attributable risk factors of stroke burden in China, 1990–2019: an analysis for the Global Burden of Disease Study 2019. *Lancet Public Health*, 2021. 6(12): p. e897–e906. [https://doi.org/10.1016/S2468-2667\(21\)00228-0](https://doi.org/10.1016/S2468-2667(21)00228-0)
- Global burden and strength of evidence for 88 risk factors in 204 countries and 811 subnational locations, 1990–2021: a systematic analysis for the Global Burden of Disease Study 2021. *Lancet*, 2024. 403(10440): p. 2162–2203. [https://doi.org/10.1016/S0140-6736\(24\)00933-4](https://doi.org/10.1016/S0140-6736(24)00933-4)
- Global, regional, and national comparative risk assessment of 84 behavioural, environmental and occupational, and metabolic risks or clusters of risks for 195 countries and territories, 1990–2017: a systematic analysis for the Global Burden of Disease Study 2017. *Lancet*, 2018. 392(10159): p. 1923–1994.

- [19] GBD Protocol. Institute for Health Metrics and Evaluation. Available at <https://www.healthdata.org/research-analysis/about-gbd/protocol>
- [20] United Nations Department of Economic and Social Affairs, Population Division (2022). World Population Prospects 2022: Summary of Results. UN DESA/POP/2022/TR/NO. 3.
- [21] Global, regional, and national burden of diabetes from 1990 to 2021, with projections of prevalence to 2050: a systematic analysis for the Global Burden of Disease Study 2021. *Lancet*, 2023. 402(10397): p. 203–234.
- [22] Liang, D., et al., Burden of type 1 and type 2 diabetes and high fasting plasma glucose in Europe, 1990-2019: a comprehensive analysis from the global burden of disease study 2019. *Front Endocrinol (Lausanne)*, 2023. 14: p. 1307432. <https://doi.org/10.3389/fendo.2023.1307432>
- [23] Cao, X., et al., Disparities in high fasting plasma glucose-related cardiovascular disease burden in China. *Nat Commun*, 2024. 15(1): p. 8817. <https://doi.org/10.1038/s41467-024-53236-y>
- [24] Wang, M., et al., Burden of liver cancer attributable to high fasting plasma glucose: a global analysis based on the global burden of disease study 2019. *J Nutr Health Aging*, 2024. 28(6): p. 100261. <https://doi.org/10.1016/j.jnha.2024.100261>
- [25] Tang, L., L. Xie, and Y. Liu, Temporal trends of ischemic stroke attributable to high fasting plasma glucose in China from the global burden of disease study 2019. *Front Endocrinol (Lausanne)*, 2024. 15: p. 1408691. <https://doi.org/10.3389/fendo.2024.1408691>
- [26] Wang, C., et al., Temporal trends in mortality of tuberculosis attributable to high fasting plasma glucose in China from 1990 to 2019: a joinpoint regression and age-period-cohort analysis. *Front Public Health*, 2023. 11: p. 1225931. <https://doi.org/10.3389/fpubh.2023.1225931>
- [27] Wei, H., et al., Global, regional, and national burden of chronic kidney disease attributable to high fasting plasma glucose from 1990 to 2019: a systematic analysis from the global burden of disease study 2019. *Front Endocrinol (Lausanne)*, 2024. 15: p. 1379634. <https://doi.org/10.3389/fendo.2024.1379634>
- [28] Li, C., et al., Global, regional, and national burden of blindness and vision loss attributable to high fasting plasma glucose from 1990 to 2019, and forecasts to 2030: A systematic analysis for the Global Burden of Disease Study 2019. *Diabetes Metab Res Rev*, 2024. 40(4): p. e3802. <https://doi.org/10.1002/dmrr.3802>
- [29] Wang, M., et al., Global Burden of Alzheimer's Disease and Other Dementias Attributed to High Fasting Plasma Glucose from 1990 to 2019. *J Prev Alzheimers Dis*, 2024. 11(3): p. 780–786. <https://doi.org/10.14283/jpad.2024.47>
- [30] Global incidence, prevalence, years lived with disability (YLDs), disability-adjusted life-years (DALYs), and healthy life expectancy (HALE) for 371 diseases and injuries in 204 countries and territories and 811 subnational locations, 1990-2021: a systematic analysis for the Global Burden of Disease Study 2021. *Lancet*, 2024. 403(10440): p. 2133–2161.
- [31] Malone, J. I. and B. C. Hansen, Does obesity cause type 2 diabetes mellitus (T2DM)? Or is it the opposite? *Pediatr Diabetes*, 2019. 20(1): p. 5–9. <https://doi.org/10.1111/pedi.12787>
- [32] Kuźbicka, K. and D. Rachoń, Bad eating habits as the main cause of obesity among children. *Pediatr Endocrinol Diabetes Metab*, 2013. 19(3): p. 106–10.
- [33] Li, Y., et al., Metabolic syndromes increase significantly with the accumulation of bad dietary habits. *J Nutr Health Aging*, 2024. 28(2): p. 100017. <https://doi.org/10.1016/j.jnha.2023.100017>
- [34] Warburton, D. E. R. and S. S. D. Bredin, Health benefits of physical activity: a systematic review of current systematic reviews. *Curr Opin Cardiol*, 2017. 32(5): p. 541–556. <https://doi.org/10.1097/HCO.0000000000000437>