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Disease burden of lung cancer attributable to metabolic and behavioral risks in China and globally from 1990 to 2021

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Abstract

Background There are differences between China and globally in the burden of lung cancer attributed to behavioral and metabolic risks.

Methods This research utilized the Global Burden of Disease (GBD) 2021 database to extract the deaths and disability-adjusted life-years (DALYs) of lung cancer attributed to metabolic and behavioral risks in China and globally, along with the age-standardized mortality rates (ASMR) and age-standardized DALYs rates (ASDR). The age-period-cohort model was used to identify age effects, period effects, cohort effects, as well as local and net drift. Decomposition analysis was used to quantify the relative contributions of aging, epidemiological change, and population to the lung cancer burden. Bayesian age-period-cohort model was used for predictive analysis.

Results From 1990 to 2021, the ASMR of lung cancer attributed to smoking and secondhand smoke significantly decreased globally, but it increased slightly in China. And the ASMR of lung cancer attributed to diet low in fruits significantly decreased, while the ASMR due to high fasting plasma glucose increased both in China and globally. The net drifts of lung cancer deaths attributed to smoking and secondhand smoke were both negative values globally, while the net drifts were small and even close to zero in China. The net drifts attributed to diet low in fruits and high fasting plasma glucose globally were -2.06% and 0.29%, respectively, and the lung cancer deaths among elderly patients has been increasing annually. However, in China, the lung cancer deaths attributed to diet low in fruits has been decreasing annually across all age groups, while the deaths due to high fasting plasma glucose has been increasing year by year. In the next 15 years, the burden of lung cancer attributed to behavioral and metabolic risks was expected to decrease in China and globally, but the burden among Chinese women attributed to smoking and secondhand smoke showed a slow upward trend.

Conclusions Over the past thirty years, the global burden of lung cancer attributed to behavioral factors has decreased, while it increased slow in attribution to metabolic factors. In China, only the lung cancer burden attributed to diet low in fruits has decrease, others have exhibited a fluctuating trend. In the next 15 years, the burden of lung cancer attributed to behavioral and metabolic risks decreases globally, but the lung cancer burden attributed to smoking and secondhand smoke shows a slow upward trend among Chinese women. That asks a need for greater attention to the tobacco exposure among women.

Keywords Lung cancer, Global disease burden, Metabolic risk, Behavioral risks, Bayesian age-period-cohort model

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Introduction

Lung cancer is the leading cause of disease burden among malignant tumors, exhibiting the highest rates of incidence and mortality. According to the Global Burden of Disease (GBD) 2019 data, the burden of lung cancer rapidly increased over the decade from 2010 to 2019, with disability-adjusted life-years (DALYs) increasing by 18.1% [1]. With population growth and aging, the incidence of lung cancer has been increasing annually. According to GLOBOCAN 2022, there were 2,480,301 new cases and 1,817,172 deaths from lung cancer globally in 2022 [2]. As the largest developing country in the world, China bears a significant burden of lung cancer [3]. The latest data indicate that in 2022, there were 1,060,600 new cases and 733,300 new deaths of lung cancer in China [4]. The disease burden and economic downturns caused by lung cancer represent severe public health challenges globally [5], necessitating effective control measure to reduce the disease burden.

The incidence and mortality of lung cancer are closely associated with various risk factors. In addition to smoking, exposure to environmental pollutants such as secondhand smoke, airborne particulate matter, and harmful compounds has also been found to influence the occurrence and progression of lung cancer [6]. Several meta-analyses suggested that insufficient fruit intake has also increased the risk of lung cancer [7, 8]. A study followed over 400,000 participants for seven years in UK Biobank and revealed that consuming 100 g of fruit daily reduced lung cancer risk by 10% [9]. In recent years, metabolic disorders have garnered increasing attention, such as obesity, elevated blood lipids and diabetes [10]. The cancer burden attributed to metabolic risks has sharply increased, primarily driven by high fasting plasma glucose and high body mass index (BMI) [11]. High plasma glucose not only affects an individual's metabolic state but may also promote inflammatory responses and alters the tumor microenvironment [12]. Several studies have found that elevated plasma glucose is a negative prognostic factor for lung cancer patients [13, 14], indicating that managing metabolic diseases is crucial to control the burden of lung cancer.

Significant differences exist in patient demographics and risk factors of lung cancer between China and the global context, necessitating different intervention strategies. However, only a few studies have compared the differences in lung cancer burden and attributable risks between the China and globally. Furthermore, existing research primarily focuses on the analysis of current epidemiology of lung cancer burden, with little emphasis on predicting the trends in the future. The GBD 2021 database categorizes the risk factors for lung cancer into three classes: metabolic risks (high fasting plasma glucose), behavioral risks (smoking, secondhand smoke, and diet low in fruits), and environmental/occupational risks. This article utilizes the GBD 2021 data to analyze the burden of lung cancer attributable to behavioral and metabolic risks in China and globally from 1990 to 2021, exploring the relative contributions of different risk factors at the population level. More importantly, we employ predictive models to analyze changes in lung cancer burden across populations over the next 15 years, aiming to provide data support for developing appropriate public health intervention measures.

Materials and methods

Data source

The data used in this study were obtained from GBD 2021, which records the incidence, prevalence, and mortality of over 300 diseases and injuries across 204 countries and territories. Our data for lung cancer were obtained from the Global Health Data Exchange (GHDx) results tool (http://ghdx.healthdata.org/gbd-results-tool). We utilized the GBD results tool to extract the number of lung cancer deaths attributable to metabolic and behavioral risks, as well as DALYs, and the corresponding age-standardized rates (ASR), specifically age-standardized mortality rates (ASMR) and age-standardized DALYs rates (ASDR). No ethics approval was required for this study due to the absence of direct involvement of humans.

Statistical analysis

In this analysis, ASMR and ASDR per 100,000 population were selected to describe the long-term trends in the burden of lung cancer. The age-period-cohort model was employed to identify age effects, period effects, cohort effects, as well as local and net drift. Decomposition analysis was utilized to quantify the relative contributions of age structure, population size, and epidemiological changes to the lung cancer burden from 1990 to 2021. Bayesian age-period-cohort (BAPC) model was employed for predictive analysis.

We used the age-period-cohort model to elucidate the impact of age, period, and cohort on lung cancer mortality and DALYs rates [15]. In this model, net drift reflected the overall temporal trend of disease mortality or DALYs rates, similar to Average Annual Percentage Change (AAPC), but differs as it simultaneously accounts for both the influences of period and cohort. Local drift was used to estimate the average annual percentage change in the mortality and DALYs rates across age groups [16]. The age effect, characterized by longitudinal age curves, primarily referred to the influence of age on the mortality and DALYs rates and represented the age-related natural progression of the mortality and DALYs. The period effect reflects the influence of social, economic, and cultural environments across different periods on mortality. The cohort effect indicates variations in disease mortality and DALYs rates due to differing levels of exposure to risk factors among various birth cohorts [17]. Relative risk (RR) is employed to assess the period and cohort effects. An intrinsic estimator based on the Poisson distribution is utilized to obtain disease parameters in this model, effectively overcoming the multicollinearity among age, period, and cohort [18]. To prevent information overlap among adjacent cohorts, the age, period, and time intervals of the cohorts must be standardized [19]. Age-period-cohort analysis is conducted using an online tool specifically designed for this purpose (http://analysistools.nci.nih.gov/apc/).

Decomposition analysis is a method to identify how variations in factors contribute to overall differences, thereby revealing significant heterogeneity in demographic and epidemiological trends [20]. We used the Das Gupta decomposition method to quantify the relative contributions of age structure, population size, and epidemiological changes to the overall burden of lung cancer from 1990 to 2021 [21, 22]. This method summarized the contributions of various factors to the observed changes by algebraically isolating the standardized effects of each contributing multiplicative factor [23]. Changes in age structure primarily reflected aging, while changes in population size were related to variations in population count. Epidemiological changes refer to age-and population-standardized rates, which associated with crude mortality and crude DALYs rates. The number of DALYs at each location was obtained from the following formula:

$$\mathrm{DALY}_{\mathrm{ay,\,py,\,ey}} = \sum_{\mathrm{i}=1}^{20}\left(\mathrm{a}_{i,y} * \mathrm{p}_{y} * \mathrm{e}_{i,y}\right)$$

Where DALY $_{\mathrm{ay,\,py,\,ey}}$ represented DALYs based on the factors of age structure, population, and DALYs rate for specific year y; a $_{\mathrm{i\,y}}$ represents the proportion of population for the age category i of the 20 age categories in given year y; p $_{\mathrm{y}}$ represents the total population in given year y; and e $_{\mathrm{i,\,y}}$ represents DALYs rate given age category i in year y. The contribution of each factor to the change in DALYs from 1990 to 2021 was defined by the effect of one factor changing while the other factors were held constant. For example, the effect of age structure was calculated as:

$$[(\mathrm{DALY}_{\mathrm{a2021,\,p1990,\,e1990}} + \mathrm{DALY}_{\mathrm{a2021,\,p2021,\,e2021}})/3 + (\mathrm{DALY}_{\mathrm{a2021,\,p1990,\,e2021}} + \mathrm{DALY}_{\mathrm{a2021,\,p2021,\,e1990}})/6] - [(\mathrm{DALY}_{\mathrm{a1990,\,p2021,\,e2021}} + \mathrm{DALY}_{\mathrm{a1990,\,p1990,\,e1990}})/3 + (\mathrm{DALY}_{\mathrm{a1990,\,p2021b,\,e1990}} + \mathrm{DALY}_{\mathrm{a1990,\,p1990,\,e2021}})/6]$$

The BAPC model has been demonstrated high coverage and is particularly effective for predicting age-stratified cancer mortality rates [24]. Based on Bayesian inference, the BAPC model allows for the incorporation of prior knowledge and uncertainty, which helps to address population-level data with inherent variability and sparsity in certain subgroups [25]. Even with limited data, this model can robustly predict mortality rates for specific age groups. This benefit is essential for predicting mortality rates of lung cancer, as it effectively infers from historical trends while accounting for uncertainty in the future. More importantly, the BAPC model can adequately explain the complex nonlinear relationships between age, period, and cohort effects, which are critical for modeling lung cancer mortality. Based on age-specific population data from 1990 to 2021, projected population data from 2022 to 2036, along with disease data and age-specific weights from GBD 2021, we applied the BAPC model to predict the ASMR and ASDR of lung cancer over the next 15 years. The BAPC model is constructed using the R packages INLA (www.r-inla.org) and BAPC (http://r-forge.r-project.org/).

Result

The burden of lung cancer in China and globally

According to GBD 2021 data, lung cancer continued to have the highest incidence and mortality rates among 28 cancer groups in China and globally (Fig. 1). Globally, lung cancer had the highest age-standardized incidence rate (ASIR) at 26.43, followed by colon and rectum cancer (25.61), breast cancer (24.56), and prostate cancer (15.37) (Table S1). In China, lung cancer also had the highest ASIR at 44.01, followed by colon and rectum cancer (31.44), stomach cancer (29.05), and breast cancer (19.36) (Table S1). The ASMR of lung cancer was 38.98 in China compared to 23.50 globally (Table S2). Following closely were colon and rectum cancer (12.40), stomach cancer (11.20) and breast cancer (7.90) globally, while in China, stomach cancer (21.51), esophageal cancer (14.13), and colon and rectum cancer (13.64) followed. Compared to other countries and regions, lung cancer in China ranks first in both incidence and mortality, with an ASIR ranking of 7th and an ASMR ranking of 9th at global (Fig. S1). The disease burden caused by lung cancer remains substantial, and the situation in China is more severe than that globally.

Fig. 1 ASIR and ASMR per 100,000 population for cancer groups at Global and China in 2021 excluding nonmelanoma skin cancer. (A)ASIR; (B) ASMR. Abbreviations: ASIR, age-standardized incidence rates; ASMR, age-standardized mortality rates

The burden of lung cancer attributed to behavioral and metabolic risks

From 1990 to 2021, the ASMR and ASDR attributed to smoking, secondhand smoke, and diet low in fruits decreased for both men and women globally, while the corresponding deaths and DALYs increased (Table 1/S3 and Fig. 2/S2). However, the ASMR attributed to high fasting plasma glucose exhibited a fluctuating upward trend. The DALYs and ASDR for global females attributed to high fasting plasma glucose both increased, while the DALYs for males also increased, but the ASDR decreased. The number of lung cancer deaths attributable to high fasting plasma glucose increased from 18,977 in 1990 to 50,547 in 2021, representing a percentage change of 166.36 (95% CI: 136.44%, 195.1%). Meanwhile, the corresponding ASMR increased from 0.49 per 100,000 to 0.59 per 100,000, representing a percentage change of 19.45%, with a notable increase of 54.73% in females. It is widely accepted that the disease burden related to high blood glucose is heavier in males than in females. However, the result showed that the percentage increase in lung cancer burden attributed to high fasting plasma glucose among females is significantly greater. That may reflect the neglect of high blood glucose management for females over the past thirty years.

In China, the number of deaths for both men and women attributed to smoking, secondhand smoke, and high fasting plasma glucose has increased annually from 1990 to 2021, while the number of deaths attributed to diet low in fruits exhibited stable fluctuations (Table 1 and Fig. 3). The ASMR for males attributed to smoking and secondhand smoke exhibited a trend of initially increasing, then decreasing, followed by another increase and a subsequent gradual decline, while the ASMR for females showed a steady decrease. The ASMR attributed to high fasting plasma glucose showed a trend of slowly rising followed by a gradual decline in males, while it remained stable in females. Notably, the ASMR attributed to diet low in fruits exhibited a downward trend in both males and females. The number of lung cancer deaths caused by diet low in fruits increased from 17,695 in 1990 to 19,148 in 2021; however, the corresponding ASMR decreased from 2.18 per 100,000 to 0.94 per 100,000 representing a percentage change of −57.12% (95% CI: −69.00%, −41.25%). The DALYs and ASDR of lung cancer attributed to behavioral and metabolic risk factors followed a trend similar to the patterns described above (Table S3 and Fig. S3). In comparison to the globally, China has performed poorly in controlling the lung cancer burden attributed to behavioral and metabolic risks over the past thirty years.

The age-period-cohort analysis of the lung cancer burden

Through the establishment of the APC model, it was found that from 1990 to 2021, the number of deaths and DALYs attributed to behavioral and metabolic risk factors increased with age, but decreased with age in older age groups in both China and globally (Fig. 4). The global lung cancer deaths and DALYs attributed to smoking, secondhand smoke, and diet low in fruits showed an RR > 1 before 2002–2006, indicating a higher relative risk of mortality, and an RR < 1 after 2002–2006, indicating a lower relative risk (Fig. 5A and 5B). However, for high fasting plasma glucose, the RR was < 1 before 2002–2006 and > 1 after 2002–2006. The analysis results for the Chinese population were similar, however, the RR of lung cancer deaths and DALYs attributed to smoking was < 1 before and after 2002–2006 (Fig. 5C and 5D). Birth cohort RR curves were plotted to explore the impact of behavioral and metabolic risk factors on the lung cancer burden across different birth cohorts in China and globally. Globally, the impact of diet low in fruits of lung cancer deaths and DALYs for

Table 1 The burden of Lung cancer Deaths and ASMR attributable to behavioral and metabolic factors in 1990 and 2021 and percentage changes from 1990 to 2021

Regions	Risk Factors	1990		2021		Percentage Changes, 1990–2021	
		Deaths (persons, 95% UI)	ASMR (95% UI)	Deaths (persons, 95% UI)	ASMR (95% UI)	Deaths (%, 95% UI)	ASMR (%, 95% UI)
Global	**Smoking**						
	Male	620,857 (577,880,669,544)	34.85 (32.37,37.57)	975,671 (843,776,1,123,054)	24.68 (21.38,28.37)	57.15 (31.66,83.99)	−29.16 (−40.4,−17.53)
	Female	117,069 (105,907,128,707)	5.55 (5,6.11)	220,125 (187,189,255,059)	4.72 (4.02,5.47)	88.03 (68.7,108.75)	−14.93 (−23.68,−5.7)
	Both	737,926 (686,229,791,982)	18.72 (17.37,20.12)	1,195,796 (1,054,670,1,359,223)	13.85 (12.22,15.74)	62.05 (39.75,85.51)	−26.03 (−36.03,−15.53)
	Secondhand smoke						
	Male	36,764 (4318,69,861)	2.03 (0.24,3.86)	56,848 (6655,109,071)	1.44 (0.17,2.78)	54.63 (25.12,89.57)	−28.65 (−42.44,−13.1)
	Female	20,854 (2762,37,840)	0.98 (0.13,1.78)	41,063 (5536,78,059)	0.89 (0.12,1.69)	96.9 (60.23,139.01)	−9.17 (−25.89,10.19)
	Both	57,618 (7083,107,842)	1.45 (0.18,2.72)	97,911 (11,955,184,913)	1.14 (0.14,2.15)	69.93 (45.22,96.94)	−21.5 (−32.76,−9.09)
	Diet low in fruits						
	Male	37,727 (18,867,56,539)	2.08 (1.05,3.11)	44,328 (22,872,64,127)	1.12 (0.58,1.63)	17.5 (−4.24,37.57)	−46.12 (−56.13,−37.12)
	Female	13,895 (7256,20,691)	0.65 (0.34,0.97)	21,717 (11,100,32,327)	0.47 (0.24,0.7)	56.3 (34.4,82.2)	−28.09 (−37.92,−16.5)
	Both	51,621 (25,770,75,860)	1.3 (0.65,1.91)	66,045 (34,006,97,033)	0.77 (0.4,1.13)	27.94 (9.3,44.62)	−40.88 (−49.33,−33.37)
	High fasting plasma glucose						
	Male	14,164 (−2874,31,397)	0.84 (−0.17,1.86)	34,001 (−6749,78,316)	0.88 (−0.17,2.02)	140.05 (106.28,174.44)	5.29 (−9.03,19.4)
	Female	4813 (−1037,10,797)	0.23 (−0.05,0.51)	16,546 (−3297,37,447)	0.35 (−0.07,0.8)	243.81 (202.46,289.35)	54.73 (36.66,75.14)
	Both	18,977 (−3911,41,995)	0.49 (−0.1,1.1)	50,547 (−10,046,115,606)	0.59 (−0.12,1.35)	166.36 (136.44,195.1)	19.45 (6.29,31.97)
China	**Smoking**						
	Male	157,910 (125,507,191,811)	42.26 (34.13,50.82)	448,269 (335,411,587,725)	45.89 (34.64,59.46)	183.88 (90.92,299.43)	8.57 (−26.28,49.54)
	Female	23,269 (18,156,28,961)	6.04 (4.75,7.49)	70,527 (52,881,93,990)	6.36 (4.8,8.39)	203.09 (114.34,322.92)	5.39 (−24.78,46.33)
	Both	181,179 (148,434,214,245)	22.66 (18.77,26.57)	518,796 (405,741,661,789)	24.53 (19.38,31.09)	186.35 (102.38,294.84)	8.25 (−22.71,47.03)
	Secondhand smoke						
	Male	10,297 (1119,20,761)	2.89 (0.31,5.83)	30,494 (3304,61,293)	3.23 (0.35,6.42)	196.13 (88.07,341.1)	11.74 (−28.27,61.52)
	Female	10,461 (1445,19,221)	2.5 (0.35,4.6)	27,541 (3758,52,697)	2.5 (0.34,4.8)	163.28 (91.02,255.18)	0.1 (−27.5,35.08)
	Both	20,758 (2564,39,187)	2.63 (0.32,4.96)	58,034 (7170,109,625)	2.8 (0.35,5.27)	179.58 (114.57,267.63)	6.45 (−17.41,37.96)
	Diet low in fruits						
	Male	12,038 (5521,19,208)	3.17 (1.48,5.06)	13,082 (6442,21,523)	1.39 (0.69,2.27)	8.68 (−31.57,64.85)	−56.01 (−72.29,−34.35)
	Female	5657 (2778,8883)	1.36 (0.65,2.13)	6065 (2949,9857)	0.56 (0.27,0.91)	7.21 (−27.77,49.74)	−58.81 (−71.96,−42.68)
	Both	17,695 (8642,27,166)	2.18 (1.07,3.31)	19,148 (9773,30,002)	0.94 (0.48,1.47)	8.21 (−22.47,49.71)	−57.12 (−69,−41.25)
	High fasting plasma glucose						
	Male	3298 (−683,7486)	0.93 (−0.19,2.08)	11,687 (−2190,27,401)	1.21 (−0.23,2.86)	254.36 (135.01,398.94)	29.89 (−13.55,80.47)
	Female	1465 (−323,3373)	0.37 (−0.08,0.84)	5726 (−1148,13,295)	0.52 (−0.1,1.19)	290.81 (184.3,439.84)	40.33 (2.55,93.06)
	Both	4763 (−1024,10,942)	0.62 (−0.13,1.41)	17,413 (−3460,39,860)	0.83 (−0.17,1.9)	265.57 (173.25,375.59)	34.24 (0.95,73.17)

Abbreviations: *ASMR* Age-standardized mortality rates, *UI* uncertainty interval.

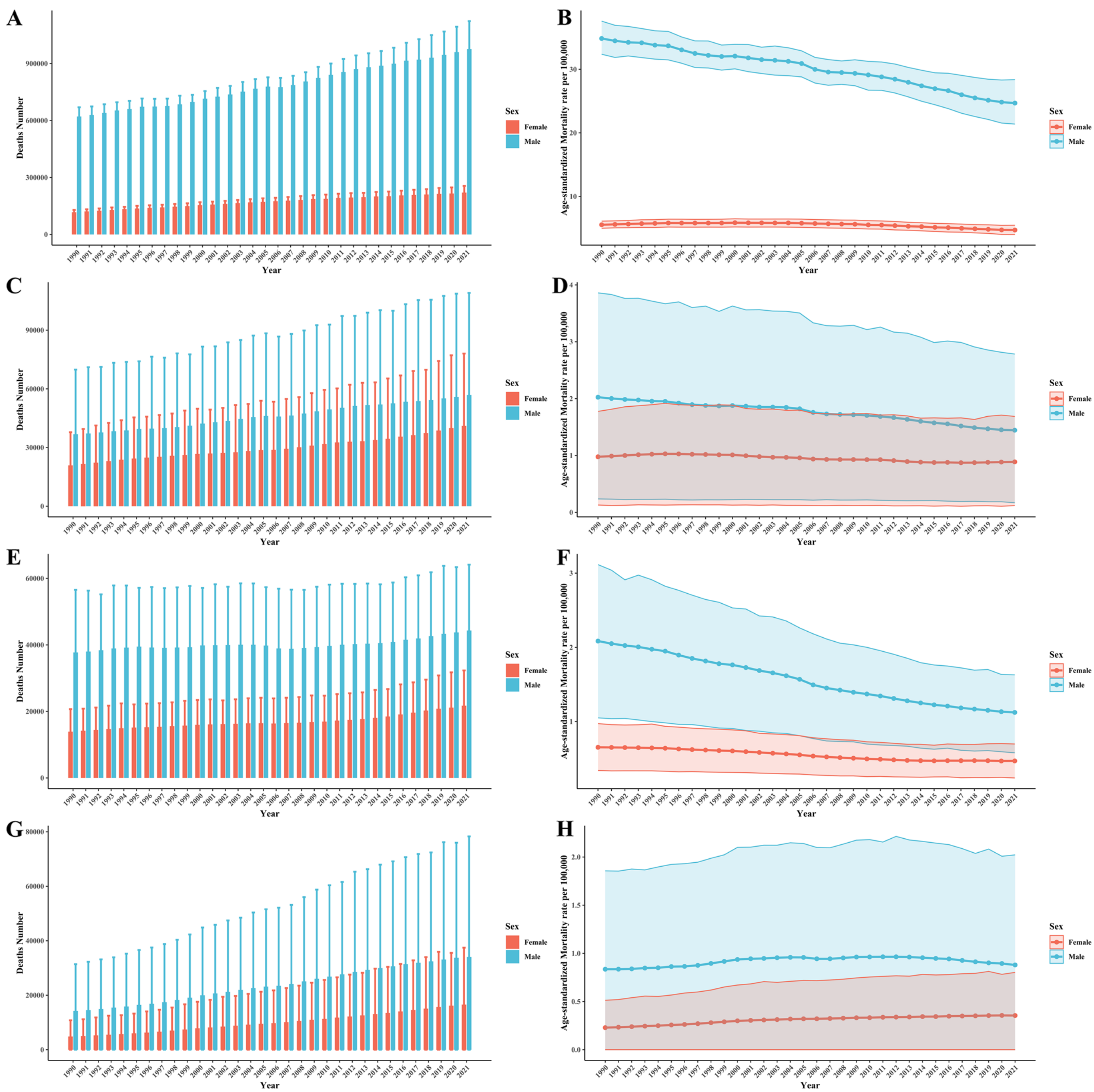

Fig. 2 Disease burden of Lung cancer deaths and ASMR in male and female attributable to behavioral and metabolic risks at Global from 1990 to 2021.(A)the deaths attributable to smoking; (B)the ASMR attributable to smoking; (C)the deaths attributable to secondhand smoke; (D)the ASMR attributable to secondhand smoke; (E)the deaths attributable to diet low in fruits; (F)the ASMR attributable to diet low in fruits; (G)the deaths attributable to high fasting plasma glucose; (H)the ASMR attributable to high fasting plasma glucose. ASMR, age-standardized mortality rates

birth cohorts born before 1920 significantly increased, while its impact on cohorts born after 1920 significantly decreased (Fig. 6A and 6B). However, in China, the impact of diet low in fruits on lung cancer deaths and DALYs had significantly decreased across all birth cohorts (Fig. 6C and 6D). The APC analysis stratified by sex are displayed in the supplement (Fig. S4-S9).

After considering the effects of both period and cohort, the net drift of smoking was −1.28% (95%CI: −1.33%, −1.23%) globally, with an annual increase in lung cancer deaths attributed to smoking after the age of 80–84 (Fig. 7A and 7B). The net drift of secondhand smoke was −1.19% (95%CI: −1.25%, −1.12%), accompanied by a yearly increase in lung cancer deaths due to secondhand smoke after the age of 80–84. The net drift of diet low

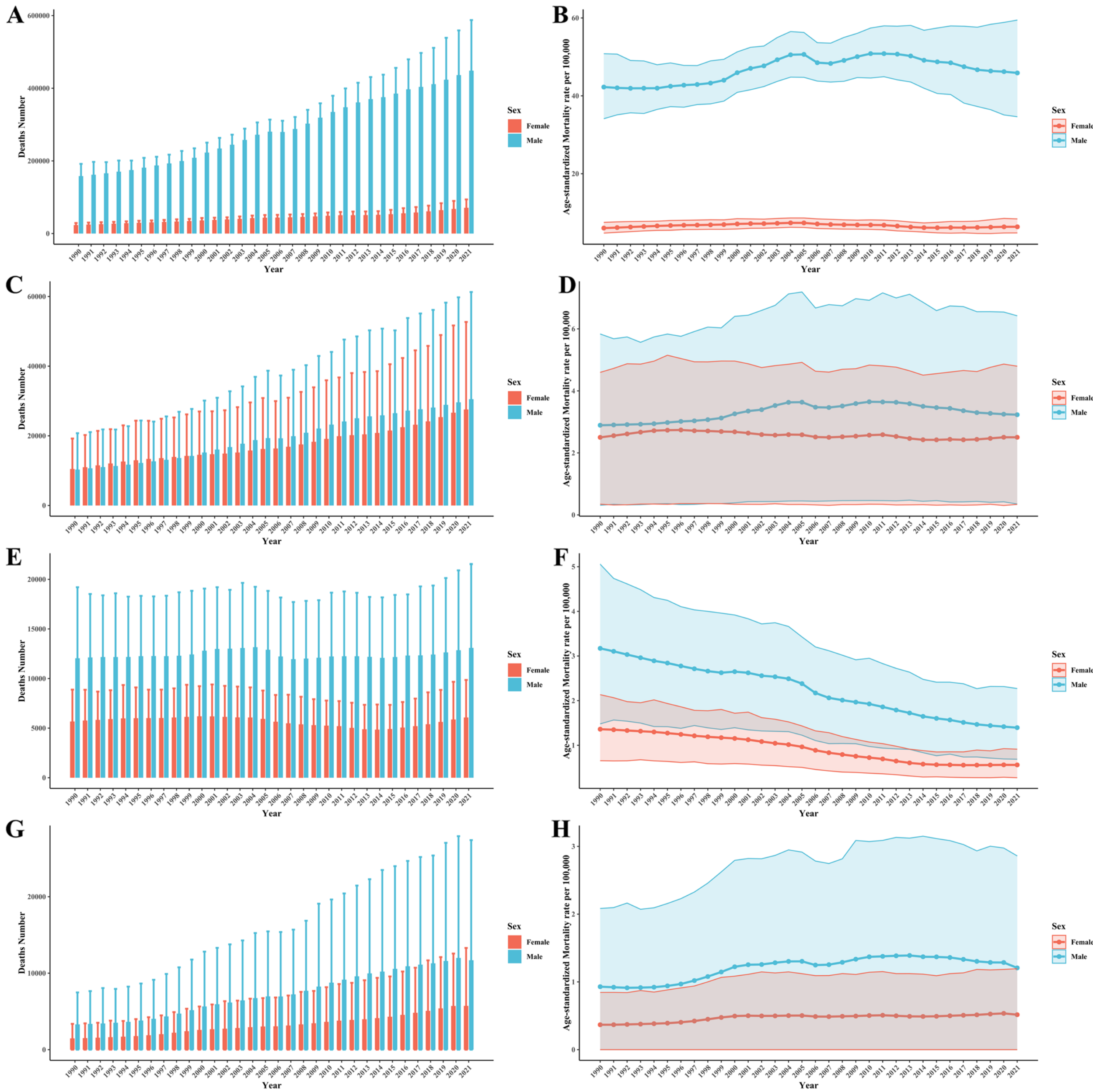

Fig. 3 Disease burden of Lung cancer deaths and ASMR in male and female attributable to behavioral and metabolic risks in China from 1990 to 2021.(A)the deaths attributable to smoking; (B)the ASMR attributable to smoking; (C)the deaths attributable to secondhand smoke; (D)the ASMR attributable to secondhand smoke; (E)the deaths attributable to diet low in fruits; (F)the ASMR attributable to diet low in fruits; (G)the deaths attributable to high fasting plasma glucose; (H)the ASMR attributable to high fasting plasma glucose. ASMR, age-standardized mortality rates

in fruits was −2.06%, with an annual increase in deaths attributed to low fruit diet after the age of 85–89. And the net drift for high fasting plasma glucose was 0.29%, with a yearly rise in deaths after the age of 60–64. However, the situation in China differed. The net drift of diet low in fruits was −3.61% (95%CI: −3.75%, −3.47%), accompanied by a yearly decrease in lung cancer deaths across all age groups attributed to a low-fruit diet (Fig. 7C and 7D). Conversely, the net drift of high fasting plasma glucose was 0.90% (95%CI: 0.69%, 1.11%), with an annual increase in lung cancer deaths across all age groups. The local drifts curves stratified by sex are displayed in the supplement (Fig. S10 and Fig. S11). This indicates that the management of the lung cancer burden attributed to smoking, secondhand smoke, and high fasting plasma glucose is less effective in China, as the trend of annual

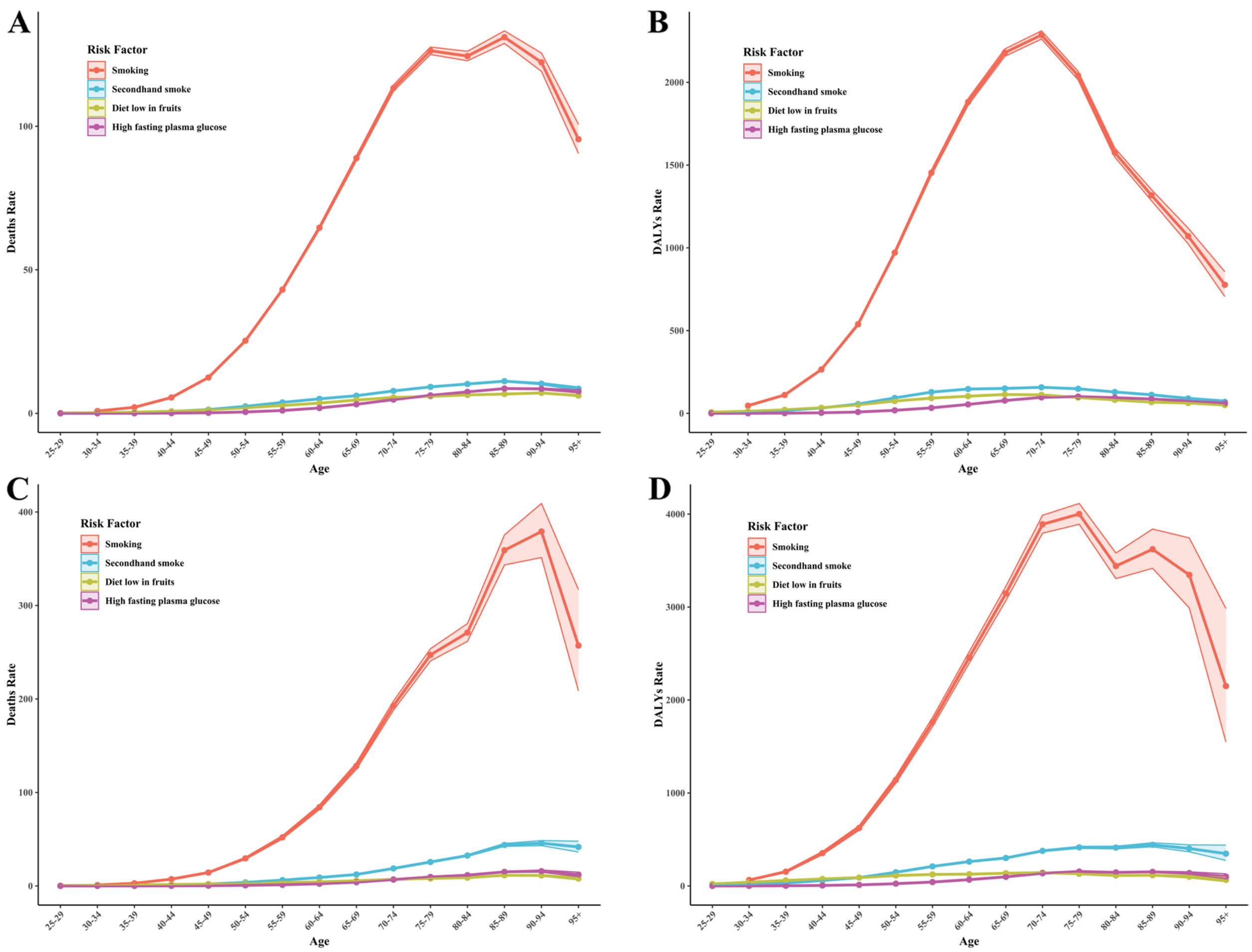

Fig. 4 Longitudinal age curve of lung cancer deaths and dALYs attributable to behavioral and metabolic risks at global and China from 1990 to 2021. (A)Global Deaths; (B)Global DALYs; (C)China Deaths; (D)China DALYs. Abbreviations: DALYs, disability adjusted life years

increasing related deaths is observed among younger elderly patients.

The contributions of aging, epidemiology change and population to the burden of lung cancer

The increase in global lung cancer deaths attributed to smoking, secondhand smoke, and diet low in fruits was primarily driven by population growth and aging, while epidemiological changes played a crucial role in reducing the number of deaths. Population growth (67.14%), aging (23.55%), and epidemiological changes (9.31%) all contributed to the increase in global lung cancer deaths attributed to high fasting plasma glucose. Over the past 30 years, aging and population growth have been the primary contributors to the increase in DALYs attributed to diet low in fruits, while epidemiological changes have played a significant role in the decrease (Fig. 8A/B and Table S4).

In China, the increase in lung cancer deaths attributed to smoking, secondhand smoke, and high fasting plasma glucose was primarily driven by population growth, aging, and epidemiological changes. Similar to the global trends, the increase in lung cancer deaths attributed to diet low in fruits was mainly due to population growth and aging, while epidemiological changes played a crucial role in reducing the number of deaths (Fig. 8C/D and Table S4). With the improvements in health awareness and healthcare accessibility, epidemiological changes have contributed to a reduction in lung cancer deaths globally caused by smoking, secondhand smoke, and diet low in fruits. However, this impact in China does not seem to have yet materialized.

The BAPC model to predict the ASMR and ASDR

The BAPC model indicated that the ASMR and ASDR of lung cancer in global males attributed to behavioral and metabolic risks are expected to decline in both Chinese and global males over the next 15 years (Fig. 9/10, Fig S4/S5, Table S5 and Table S6). For global females, only the lung cancer burden attributed to smoking is

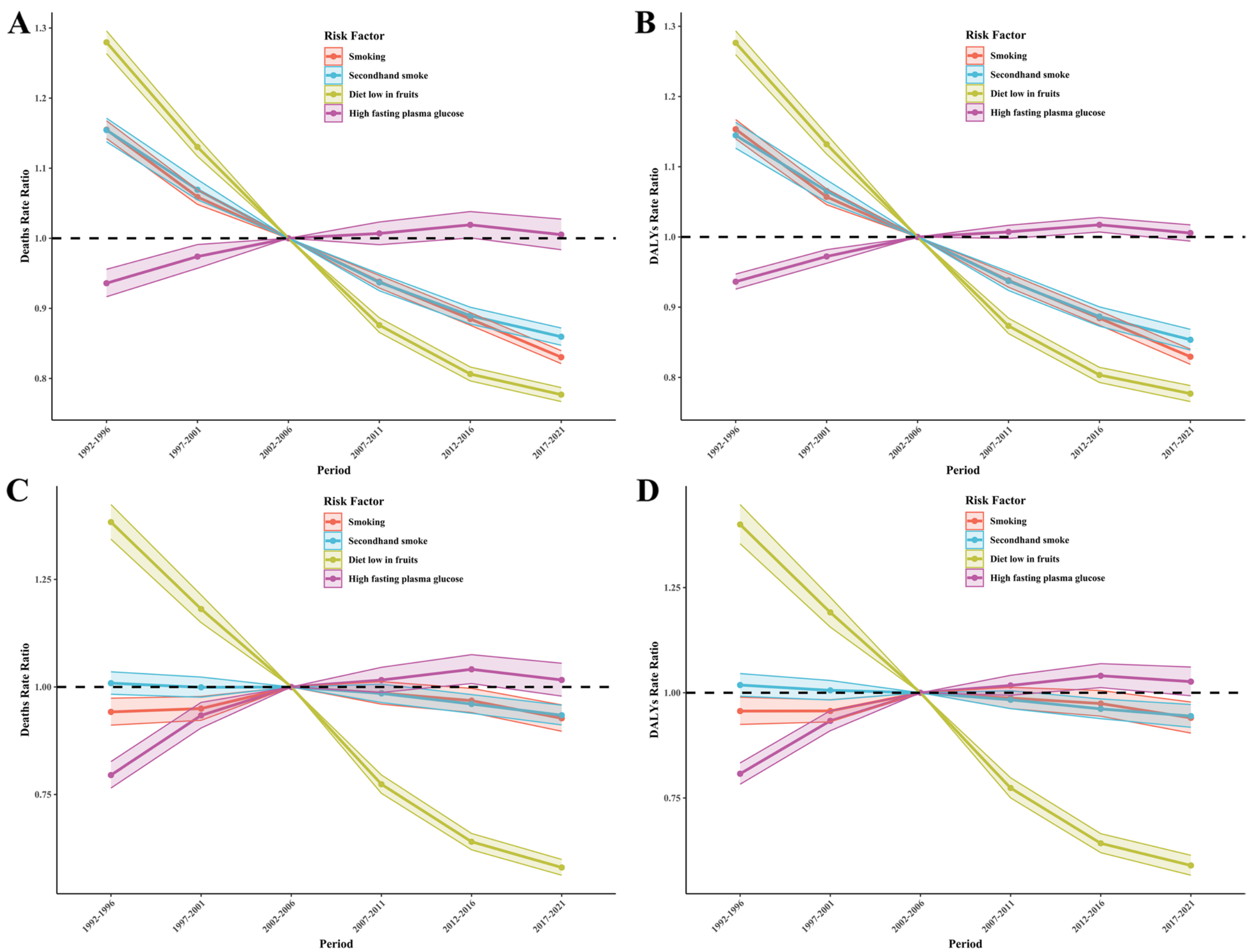

Fig. 5 Period RR curve of lung cancer deaths and DALYs attributable to behavioral and metabolic risks at global and China from 1990 to 2021. (A) Global Deaths; (B)Global DALYs; (C)China Deaths; (D)China DALYs. Abbreviations: DALYs, disability adjusted life years

also expected to significantly decrease (Fig. 9, Fig. S4, Table S7 and Table S8). Notably, in Chinese females, the ASMR and ASDR of lung cancer attributed to smoking and secondhand smoke are expected to slowly increase over the next 15 years, with the ASMR projected to rise from 6.373 per 100,000 to 6.801 per 100,000 and the ASDR projected to increase from 126.482 per 100,000 to 129.373 per 100,000 (Fig. 10, Fig. S5, Table S7 and Table S8). The unexpected projected increase suggests that existing anti-smoking policies and health education are still insufficient in reducing tobacco exposure among women, particularly Chinese women. Further investigation into the factors affecting tobacco exposure and the formulation of effective anti-smoking policies in females is essential.

Discussion

Based on the GBD 2021 database, we compared the disease burden of lung cancer caused by behavioral and metabolic risks between China and globally, and predicted the future trends. From 1990 to 2021, the global lung cancer burden attributable to smoking and secondhand smoke has continuously decreased. Since the relationship between smoking and lung cancer was first established in 1950, smoking has been regarded as the primary cause of lung cancer. Recent studies have consistently elucidated the mechanisms through which various carcinogens in tobacco mediated the progression of lung cancer [26–28]. According to the WHO, the smoking rate among males is generally higher than that among females, contributing to a greater lung cancer burden in males. Tobacco exposure is also a risk factor for various pulmonary diseases and chronic

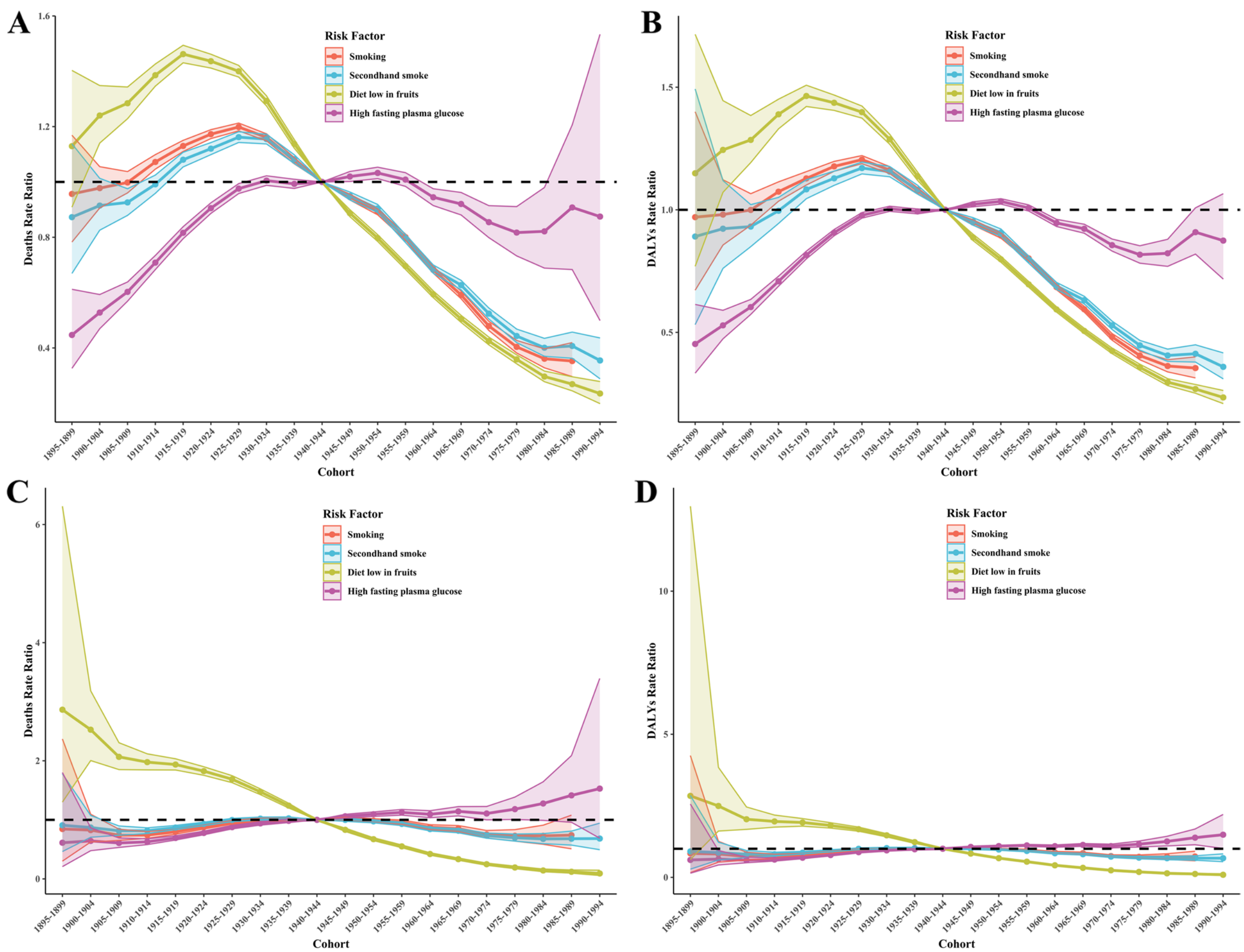

Fig. 6 Cohort RR curve of lung cancer deaths and DALYs attributable to behavioral and metabolic risks at global and China from 1990 to 2021. (A) Global Deaths; (B)Global DALYs; (C)China Deaths; (D)China DALYs. Abbreviations: DALYs, disability adjusted life years

conditions, which further exacerbate the mortality risk for patients. Notably, the results of the APC model indicate that the lung cancer burden caused by smoking and secondhand smoke in elderly patients continue to increase annually after controlling for the effects of time and cohort. Compared to younger, the elderly are exposed to tobacco and environmental pollutants for a longer time. Moreover, the cumulative effects further exacerbate the lung cancer burden [29]. This suggests that health interventions related to smoking for the elderly should not be neglected.

The results of the period analysis show a high risk of lung cancer deaths due to smoking and secondhand smoke before 2002–2006. As the time going, the relative risk on smoking has significantly decreased. The change is closely related to the strengthened smoking cessation policies globally, such as the implementation of the Framework Convention on Tobacco Control in 2005 and legislation by governments to ban smoking in public places [30]. These policies have effectively reduced smoking rates and secondhand smoke exposure, thereby lowering lung cancer deaths. However, the lung cancer burden attributable to smoking in China is more severe, with no significant decline observed before 2015. The results of the APC model also show an increase in disease burden among younger elderly individuals compared to the globally. Ineffective implementation of smoking cessation policies, poor public health education, and socioeconomic factors may be contributing to this situation. The Chinese government needs to enhance its support for public health, such as increasing tobacco taxes, promoting smoking cessation services, and restricting tobacco advertising.

Predictions indicate that the burden of lung cancer attributable to smoking and secondhand smoke among Chinese females is expected to rise over the next 15 years, while it is anticipated to continue declining among males. Various carcinogens present in tobacco

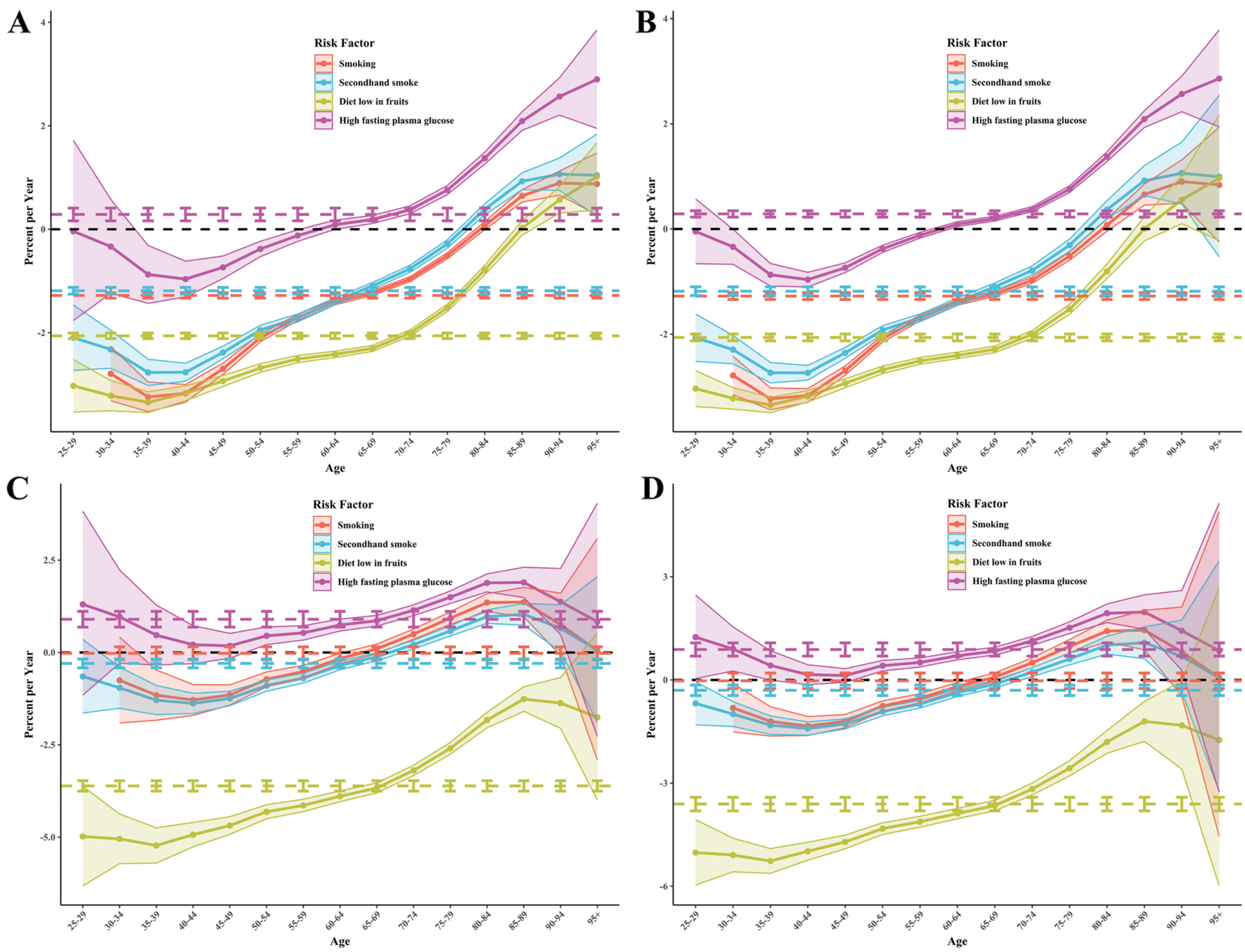

Fig. 7 Local drifts curve of lung cancer deaths and DALYs attributable to behavioral and metabolic risks at global and China with net drifts from 1990 to 2021. (A)Global Deaths; (B)Global DALYs; (C)China Deaths; (D)China DALYs. Abbreviations: DALYs, disability adjusted life years

are major contributors to lung adenocarcinoma, the most common pathological type among non-smoking females [31, 32]. Potential reasons for the increased susceptibility to lung cancer among female smokers include the interaction of tobacco carcinogens with estrogen and their vulnerability to mutations in the P53 and KRAS genes [33]. Clinical data indicated that the absolute risk of lung adenocarcinoma in women with no tobacco exposure was 2.5%, while the incidence risk for those exposed to tobacco at home or work was 3.7%, and for exposed to both reached 5.3% [34]. These researches indicated that the harm of tobacco exposure to women should not be underestimated and public health efforts should enhance attention to them. Establishing specific quitline and counseling services for women are feasible, along with launching tobacco harm awareness campaigns and offering tailored cessation plans. Further, stricter smoking bans in public areas (like restaurants, shopping malls, and public transport) should be enforced to protect females from secondhand smoke. Researchers can conduct more studies on tobacco exposure and health damage among females to provide data support for policy formulation.

In addition to cigarettes, there is increasing evidence suggesting that dietary factors may influence the risk of lung cancer. A meta-analysis involving 20,213 patients demonstrated that an increase in fruit intake could reduce the risk of lung cancer by approximately 20% [35]. Numerous antioxidants present in fruits and vegetables, such as β-cryptoxanthin, have been shown to facilitate the repair of smoking-induced inflammation, DNA damage, and squamous metaplasia in the lungs [36]. Phytochemicals, including isothiocyanates and indoles found in fruits and vegetables, can inhibit tumor cell proliferation and induce apoptosis through various mechanisms [37, 38]. Furthermore, some components also reduce C-reactive protein and interleukins, thereby helping to regulate inflammatory responses and diminish lung cancer risk [39]. A study

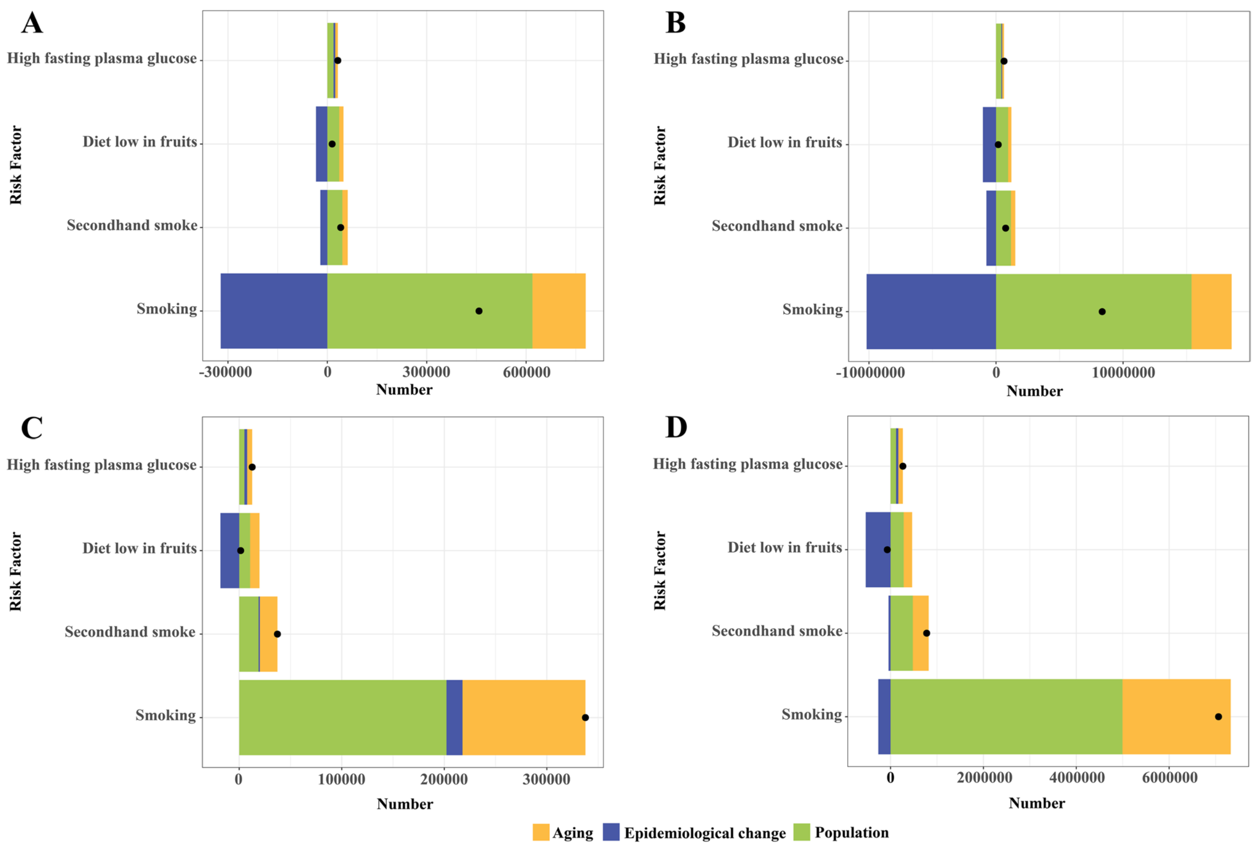

Fig. 8 Relative contributions of population aging, population growth and epidemiological changes to Lung cancer deaths and DALYs attributable to behavioral and metabolic risks from 1990 to 2021. (A)Global Deaths; (B)Global DALYs; (C)China Deaths; (D)China DALYs. Abbreviations: DALYs, disability adjusted life years

found that the intake of vitamin K was negatively correlated with lung cancer risk based on 564,127 person-years of follow-up [40]. The APC analysis showed that the lung cancer deaths attributable to diet low in fruits significantly decreased in cohorts born after 1920, which may be related to economic development, the spread of nutritional education and the promotion of healthy dietary policies. Since the introduction of the first Nutrition Pyramid by the U.S. Department of Agriculture in 1992, balanced diets have been increasingly emphasized, resulting in a gradual shift towards a more balanced and healthier dietary structure. These findings are consistent with our study, which suggested that the lung cancer burden attributable to low fruit diet in both China and globally was decreasing annually and likely to continue this downward trend over the next 15 years.

In recent years, the healthy threat posed by high plasma glucose has been growing more serious. Our study also shows that the burden of lung cancer attribute to high fasting plasma glucose is gradually increasing in both China and globally. Changes in the metabolic environment caused by hyperglycemia lead to increased tumor incidence and cancer-related mortality through various pathways, including direct effects on tumor cell metabolism and the promotion of an immunosuppressive microenvironment [41]. Oxidative stress induced by hyperglycemia has been found to accelerate the metastasis of tumor cells, and the removal of hydrogen peroxide through peroxidase can effectively inhibit tumor metastasis progression in hyperglycemic mouse models [42]. A recent study has shown that tobacco-induced hyperglycemia accelerated lung cancer progression by promoting paracrine signaling of IGF2/IR/NPM1/PD-L1 [27]. A study involving 1,279 advanced NSCLC patients demonstrated that diabetic patients with poor glycemic control (HbA1c > 6.6%) had significantly shorter survival than non-diabetic patients or those with good glycemic control [43]. The increasing of lung cancer deaths attributed to high fasting plasma glucose may be related to the global prevalence of diabetes and metabolic syndrome, which reflects the long-term health harm of lifestyle changes such as lack of exercise, sedentary behavior, and poor dietary habits [44, 45]. According to data from Global Diabetes Atlas published in 2023, there were

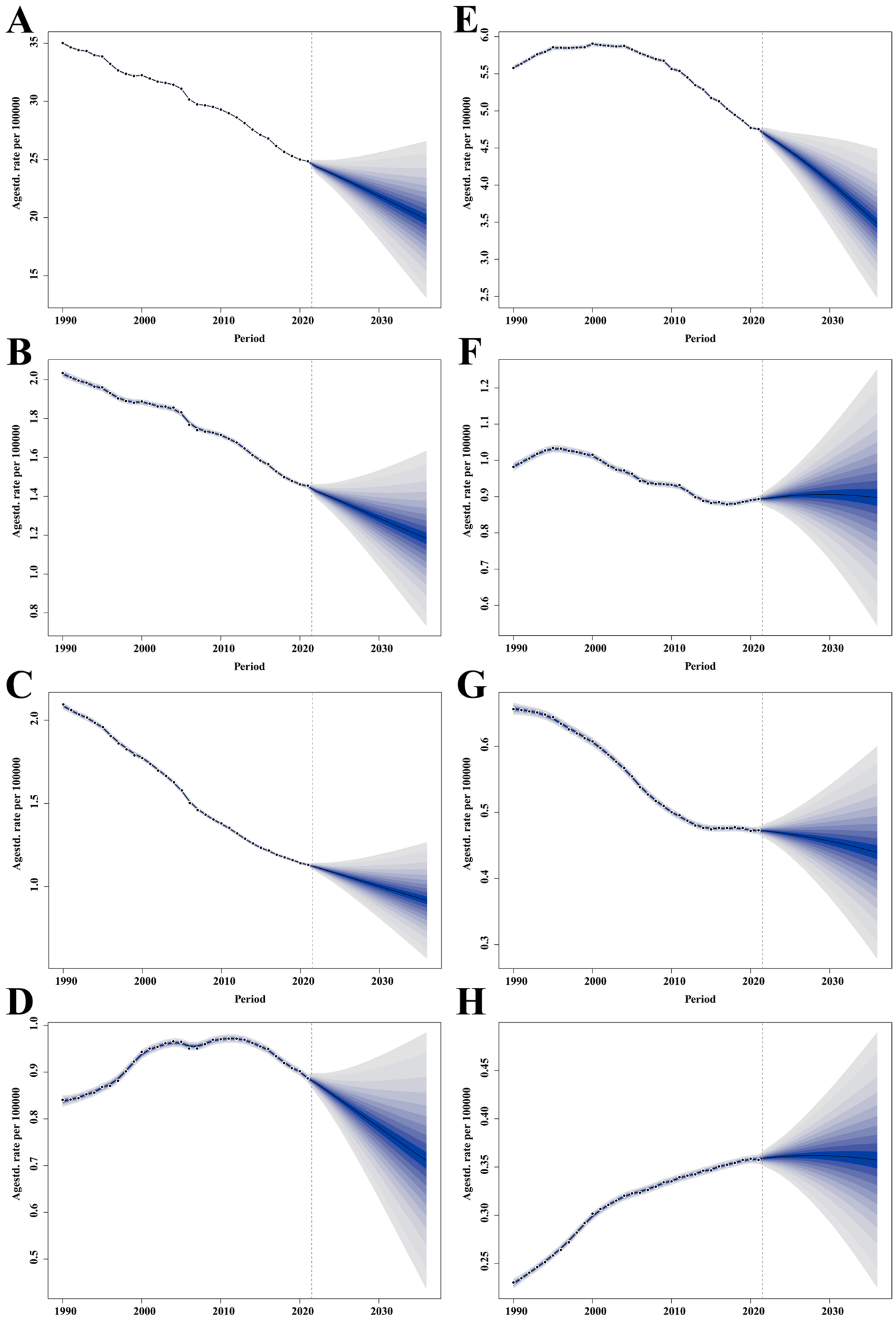

Fig. 9 Observed and predicted trends of Lung cancer ASMR attributable to behavioral and metabolic risks in male and female at global from 2022 to 2036 using the BAPC model. (A)Smoking in male; (B)Secondhand smoke in male; (C)Diet low in fruits in male; (D)High fasting plasma glucose in male; (E)Smoking in female; (F)Secondhand smoke in female; (G)Diet low in fruits in female; (H)High fasting plasma glucose in female. Abbreviations: ASMR, age-standardized mortality rates; BAPC, Bayesian age-period-cohort

537 million patients with diabetes and 298 million individuals with impaired fasting glucose in 2021, and this number continues to rise. The mortality rate from lung cancer attributable to high fasting plasma glucose has gradually increased over the past thirty years, with a greater increase observed in females compared to males. Although previous studies have suggested that men with high plasma glucose have a higher cancer mortality risk

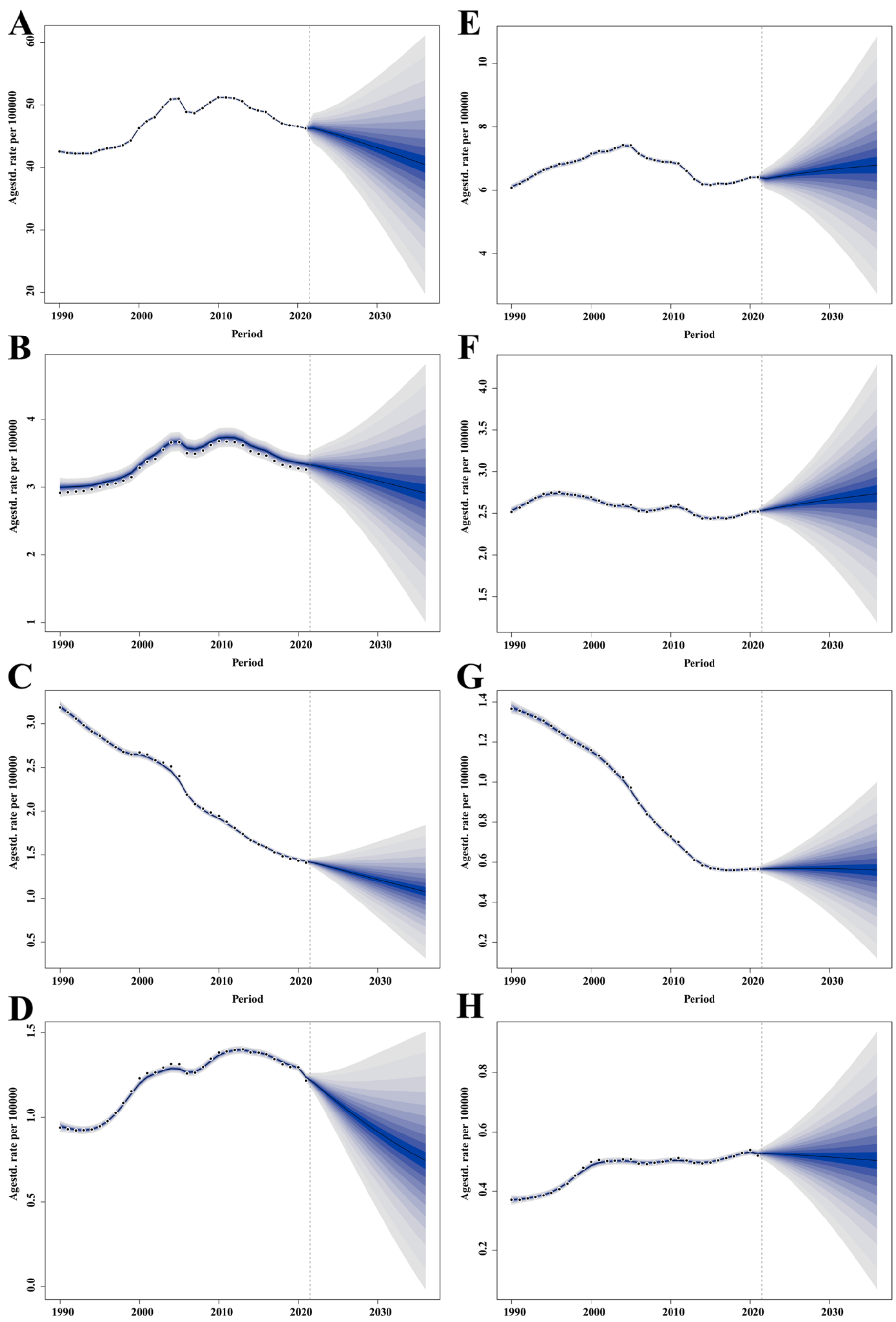

Fig. 10 Observed and predicted trends of Lung cancer ASMR attributable to behavioral and metabolic risks in male and female in China from 2022 to 2036 using the BAPC model. (A)Smoking in male; (B)Secondhand smoke in male; (C)Diet low in fruits in male; (D)High fasting plasma glucose in male; (E)Smoking in female; (F)Secondhand smoke in female; (G)Diet low in fruits in female; (H)High fasting plasma glucose in female. Abbreviations: ASMR, age-standardized mortality rates; BAPC, Bayesian age-period-cohort

than women due to the protective effects of estrogen [46]. However, the rapid increase in disease burden among women is concerning. Data from the GBD database indicated that the age-standardized average fasting plasma glucose level increases by 0.07 mmol/L every decade for men and by 0.09 mmol/L for women [47]. According to prediction, the burden of lung cancer in males due to high fasting plasma glucose would be controlled over the next 15 years, while this risk will continue to rise in women and show a decline expected between 2025 and 2030. Strategies for controlling high plasma glucose should be integrated into individual daily lives. Therefore, we have proposed some reference solutions. Firstly, conduct educational lectures especially targeting women, to deepen their understanding of the necessity for glycemic control and enhance the capability of self-monitoring. Utilize community events and cooking classes to promote healthy dietary habits, encouraging residents to boost their intake of dietary fiber and reduce consumption of sugars and high-calorie foods. In addition, the community can regularly organize exercise sessions, encourages participation in aerobic activities and strength training to help keep fit and maintain plasma glucose levels.

Limitation

This article still has some limitations, although we have tried to avoid them. Firstly, GBD 2021 database provides extensive global data, but there may be biases in data collection and reporting, especially in low- and middle-income countries, which could lead to underreporting of certain risk factors and disease burdens. Secondly, the BAPC model is based on specific assumptions that may not fully align with reality, limiting the reliability and generalizability of the results. Third, metabolic factors include high plasma glucose, obesity, dyslipidemia, etc. However, we only assessed the impact of high fasting blood glucose on lung cancer burden due to the limitations of the GBD database. Moreover, our analysis focused solely on the impact of behavioral and metabolic risks on deaths and DALYs, without addressing their effects on lung cancer incidence. Finally, the outcome is classified as lung cancer without specific staging or classification, which limits further exploration of various lung cancer types.

Conclusion

In conclusion, the burden of lung cancer attributed to behavioral and metabolic factors in China and globally is expected to continue declining, although some cohorts still exhibit an upward trend. It is crucial to focus on monitoring and intervening in smoking and secondhand smoke exposure among Chinese females. Additionally, the effects of metabolic disorders must not be overlooked, particularly among women. In light of these results, we recommend formulating public health policies targeting women, enhancing the supervision and intervention of the harms caused by smoking and secondhand smoke. At the same time, we should also focus on the relationship between metabolic disorders and lung cancer and conduct relevant research to identify high-risk individuals. Future researches should focus on the impact of behavioral metabolic factors in different populations and explore effective intervention strategies to reduce lung cancer burden.

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Authors' contributions
Lijun Li and Xiaoxin Zhang contributed equally to this manuscript. They searched the literature, analyzed the data, interpreted the results, and drafted the manuscript. Anqi Jiang, Xiaotian Guo and Guangrui Li provided support in the collection and initial analysis of the data. Minghui Zhang and Haihong Pu conceived the study, designed the study, supervised the study, interpreted the results, and revised the manuscript. All authors approved the final version of the manuscript.

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Data availability
No datasets were generated or analysed during the current study.

Declarations

Ethics approval and consent to participate
The study does not involve any ethical problem and data collection was completed in accordance with the ethical regulations.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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References

1. Kocarnik JM, Compton K, Dean FE, Fu W, Gaw BL, Harvey JD, Henrikson HJ, Lu D, Pennini A, Xu R, et al. Cancer Incidence, Mortality, Years of Life Lost, Years Lived With Disability, and Disability-Adjusted Life Years for 29 Cancer Groups From 2010 to 2019: A Systematic Analysis for the Global Burden of Disease Study 2019. JAMA Oncol. 2022;8(3):420–44.
2. Bray F, Laversanne M, Sung H, Ferlay J, Siegel RL, Soerjomataram I, Jemal A. Global cancer statistics 2022: GLOBOCAN estimates of incidence and mortality worldwide for 36 cancers in 185 countries. CA Cancer J Clin. 2024;74(3):229–63.
3. Qiu H, Cao S, Xu R. Cancer incidence, mortality, and burden in China: a time-trend analysis and comparison with the United States and United Kingdom based on the global epidemiological data released in 2020. Cancer communications (London, England). 2021;41(10):1037–48.
4. Han B, Zheng R, Zeng H, Wang S, Sun K, Chen R, Li L, Wei W, He J. Cancer incidence and mortality in China, 2022. Journal of the National Cancer Center. 2024;4(1):47–53.
5. Chen S, Cao Z, Prettner K, Kuhn M, Yang J, Jiao L, Wang Z, Li W, Geldsetzer P, Bärnighausen T, et al. Estimates and Projections of the Global Economic Cost of 29 Cancers in 204 Countries and Territories From 2020 to 2050. JAMA Oncol. 2023;9(4):465–72.
6. Huang Y, Zhu M, Ji M, Fan J, Xie J, Wei X, Jiang X, Xu J, Chen L, Yin R, et al. Air Pollution, Genetic Factors, and the Risk of Lung Cancer: A Prospective Study in the UK Biobank. Am J Respir Crit Care Med. 2021;204(7):817–25.

7. Wang C, Yang T, Guo XF, Li D. The Associations of Fruit and Vegetable Intake with Lung Cancer Risk in Participants with Different Smoking Status: A Meta-Analysis of Prospective Cohort Studies. Nutrients. 2019;11(8):1791.
8. Wang J, Gao J, Xu HL, Qian Y, Xie L, Yu H, Qian BY. Citrus fruit intake and lung cancer risk: A meta-analysis of observational studies. Pharmacol Res. 2021;166: 105430.
9. Wei X, Zhu C, Ji M, Fan J, Xie J, Huang Y, Jiang X, Xu J, Yin R, Du L, et al. Diet and Risk of Incident Lung Cancer: A Large Prospective Cohort Study in UK Biobank. Am J Clin Nutr. 2021;114(6):2043–51.
10. Li M, Cao SM, Dimou N, Wu L, Li JB, Yang J. Association of Metabolic Syndrome With Risk of Lung Cancer: A Population-Based Prospective Cohort Study. Chest. 2024;165(1):213–23.
11. Xing QQ, Li JM, Chen ZJ, Lin XY, You YY, Hong MZ, Weng S, Pan JS. Global burden of common cancers attributable to metabolic risks from 1990 to 2019. Med (New York, NY). 2023;4(3):168-81.e3.
12. Wu B, Ye Y, Xie S, Li Y, Sun X, Lv M, Yang L, Cui N, Chen Q, Jensen LD, et al. Megakaryocytes Mediate Hyperglycemia-Induced Tumor Metastasis. Can Res. 2021;81(21):5506–22.
13. Kong M, Lim YJ. Chronic hyperglycemia is an adverse prognostic factor for locoregional recurrence-free survival in small cell lung cancer patients treated with radical radiotherapy. Thoracic cancer. 2022;13(18):2633–40.
14. Cortellini A, D'Alessio A, Cleary S, Buti S, Bersanelli M, Bordi P, Tonini G, Vincenzi B, Tucci M, Russo A, et al. Type 2 Diabetes Mellitus and Efficacy Outcomes from Immune Checkpoint Blockade in Patients with Cancer. Clinical cancer research : an official journal of the American Association for Cancer Research. 2023;29(14):2714–24.
15. Zhang R, He Y, Wei B, Lu Y, Zhang J, Zhang N, He R, Xue H, Zhu B. Nasopharyngeal Carcinoma Burden and Its Attributable Risk Factors in China: Estimates and Forecasts from 1990 to 2050. Int J Environ Res Public Health. 2023;20(4):2926.
16. Chen H, Zhou Z, Li Z, Liang S, Zhou J, Zou G, Zhou S: Time trends in the burden of stroke and subtypes attributable to PM2.5 in China from 1990 to 2019. Front Public Health. 2022;10:1026870.
17. Zhu B, Wang Y, Zhou W, Jin S, Shen Z, Zhang H, Zhang X, Ding X, Li Y. Trend dynamics of gout prevalence among the Chinese population, 1990–2019: A joinpoint and age-period-cohort analysis. Front Public Health. 2022;10:1008598.
18. Yu Z, Zhang J, Lu Y, Zhang N, Wei B, He R, Mao Y. Musculoskeletal Disorder Burden and Its Attributable Risk Factors in China: Estimates and Predicts from 1990 to 2044. Int J Environ Res Public Health. 2023;20(1):840.
19. Wei J, Chen L, Huang S, Li Y, Zheng J, Cheng Z, Xie Z. Time Trends in the Incidence of Spinal Pain in China, 1990 to 2019 and Its Prediction to 2030: The Global Burden of Disease Study 2019. Pain Ther. 2022;11(4):1245–66.
20. Shu Y, Wu Z, Yang X, Song M, Ye Y, Zhang C, Yuan Q, Wang L. The burden of epilepsy in the People's Republic of China from 1990 to 2019: epidemiological trends and comparison with the global burden of epilepsy. Front Neurol. 2023;14:1303531.
21. Das Gupta P. Standardization and decomposition of rates from cross-classified data. Genus. 1994;50(3–4):171–96.
22. Chevan A, Sutherland M. Revisiting Das Gupta: refinement and extension of standardization and decomposition. Demography. 2009;46(3):429–49.
23. Estimation of the global prevalence of dementia in 2019 and forecasted prevalence in 2050: an analysis for the Global Burden of Disease Study 2019. The Lancet Public health 2022, 7(2):e105-e25.
24. Riebler A, Held L. Projecting the future burden of cancer: Bayesian age-period-cohort analysis with integrated nested Laplace approximations. Biom J. 2017;59(3):531–49.
25. Bell A, Jones K. Bayesian informative priors with Yang and Land's hierarchical age–period–cohort model. Qual Quant. 2015;49(1):255–66.
26. He H, He MM, Wang H, Qiu W, Liu L, Long L, Shen Q, Zhang S, Qin S, Lu Z, et al. In Utero and Childhood/Adolescence Exposure to Tobacco Smoke, Genetic Risk, and Lung Cancer Incidence and Mortality in Adulthood. Am J Respir Crit Care Med. 2023;207(2):173–82.
27. Jang HJ, Min HY, Kang YP, Boo HJ, Kim J, Ahn JH, Oh SH, Jung JH, Park CS, Park JS, et al. Tobacco-induced hyperglycemia promotes lung cancer progression via cancer cell-macrophage interaction through paracrine IGF2/IR/NPM1-driven PD-L1 expression. Nat Commun. 2024;15(1):4909.
28. Han G, Sinjab A, Rahal Z, Lynch AM, Treekitkarnmongkol W, Liu Y, Serrano AG, Feng J, Liang K, Khan K, et al. An atlas of epithelial cell states and plasticity in lung adenocarcinoma. Nature. 2024;627(8004):656–63.
29. DeSantis CE, Miller KD, Dale W, Mohile SG, Cohen HJ, Leach CR, Goding Sauer A, Jemal A, Siegel RL: Cancer statistics for adults aged 85 years and older, 2019. CA: a cancer journal for clinicians 2019, 69(6):452–67.
30. Monshi SS, Ibrahim J. Implementation of tobacco control measures in the Gulf Cooperation Council countries, 2008–2020. Substance abuse treatment, prevention, and policy. 2021;16(1):57.
31. Hecht SS, Carmella SG, Murphy SE, Akerkar S, Brunnemann KD, Hoffmann D. A tobacco-specific lung carcinogen in the urine of men exposed to cigarette smoke. N Engl J Med. 1993;329(21):1543–6.
32. Maclure M, Katz RB, Bryant MS, Skipper PL, Tannenbaum SR. Elevated blood levels of carcinogens in passive smokers. Am J Public Health. 1989;79(10):1381–4.
33. Stapelfeld C, Dammann C, Maser E. Sex-specificity in lung cancer risk. Int J Cancer. 2020;146(9):2376–82.
34. Blechter B, Chien LH, Chen TY, Chang IS, Choudhury PP, Hsiao CF, Shu XO, Wong JYY, Chen KY, Chang GC, et al. Polygenic Risk Score, Environmental Tobacco Smoke, and Risk of Lung Adenocarcinoma in Never-Smoking Women in Taiwan. JAMA Netw Open. 2023;6(11): e2339254.
35. Wang M, Qin S, Zhang T, Song X, Zhang S. The effect of fruit and vegetable intake on the development of lung cancer: a meta-analysis of 32 publications and 20,414 cases. Eur J Clin Nutr. 2015;69(11):1184–92.
36. Liu C, Bronson RT, Russell RM, Wang XD. β-Cryptoxanthin supplementation prevents cigarette smoke-induced lung inflammation, oxidative damage, and squamous metaplasia in ferrets. Cancer Prev Res (Phila). 2011;4(8):1255–66.
37. Amararathna M, Johnston MR, Rupasinghe HP. Plant Polyphenols as Chemopreventive Agents for Lung Cancer. Int J Mol Sci. 2016;17(8):1352.
38. Guo T, Liu C, Gao Z, He Y. Study on Effects and Mechanisms of Phytochemicals in Vegetables and Fruits in Preventing and Treating Lung Cancer. Chinese J lung cancer. 2017;20(12):841–6.
39. Dreher ML. Whole Fruits and Fruit Fiber Emerging Health Effects. Nutrients. 2018;10(12):1833.
40. Yan F, Eshak ES, Arafa A, Tamakoshi A, Iso H. Vitamin K Intake and Risk of Lung Cancer: The Japan Collaborative Cohort Study. J Epidemiol. 2023;33(10):536–42.
41. Gallagher EJ, LeRoith D. Obesity and Diabetes: The Increased Risk of Cancer and Cancer-Related Mortality. Physiol Rev. 2015;95(3):727–48.
42. Ikemura M, Nishikawa M, Kusamori K, Fukuoka M, Yamashita F, Hashida M. Pivotal role of oxidative stress in tumor metastasis under diabetic conditions in mice. Journal of controlled release : official journal of the Controlled Release Society. 2013;170(2):191–7.
43. Qian J, Wang W, Wang L, Lu J, Zhang L, Zhang B, Wang S, Nie W, Zhang Y, Lou Y, et al. The Survival Benefit for Optimal Glycemic Control in Advanced Non-Small Cell Lung Cancer Patients With Preexisting Diabetes Mellitus. Front Oncol. 2021;11: 745150.
44. Acosta-Manzano P, Leopold-Posch B, Simmons D, Devlieger R, Galjaard S, Corcoy R, Adelantado JM, Dunne F, Harreiter J, Kautzky-Willer A, et al. The unexplored role of sedentary time and physical activity in glucose and lipid metabolism-related placental mRNAs in pregnant women who are obese: the DALI lifestyle randomised controlled trial. BJOG : an international journal of obstetrics and gynaecology. 2022;129(5):708–21.
45. Silva FM, Duarte-Mendes P, Teixeira AM, Soares CM, Ferreira JP. The effects of combined exercise training on glucose metabolism and inflammatory markers in sedentary adults: a systematic review and meta-analysis. Sci Rep. 2024;14(1):1936.
46. Wu M, Lu J, Yang Z, Shen P, Yu Z, Tang M, Jin M, Lin H, Chen K, Wang J. Longitudinal changes in fasting plasma glucose are associated with risk of cancer mortality: A Chinese cohort study. Cancer Med. 2021;10(15):5321–8.
47. Liang R, Feng X, Shi D, Yang M, Yu L, Liu W, Zhou M, Wang X, Qiu W, Fan L, et al. The global burden of disease attributable to high fasting plasma glucose in 204 countries and territories, 1990–2019: An updated analysis for the Global Burden of Disease Study 2019. Diabetes Metab Res Rev. 2022;38(8): e3572.

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