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ORIGINAL ARTICLE

Lung cancer mortality trends in China from 2013 to 2021 and projections to 2030

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ABSTRACT

Objective: This study was aimed at analyzing temporal trends in lung cancer mortality from 2013 to 2021, and projecting future trends until 2030.

Methods: Mortality data were extracted from the China Causes of Death Surveillance Dataset, which covers 2.37 billion person-years. Age-standardized mortality rates (ASMRs) were calculated with Segi's world standard population. Joinpoint regression was used to analyze temporal trends, and linear regression was applied to assess changes in mean age at death. A Bayesian age-period-cohort model was used to project mortality trends through 2030. Contributions of risk factors and demographic changes (population size and age structure) to mortality trends were decomposed with the population split method.

Results: From 2013 to 2021, the crude lung cancer mortality rate increased by 2.3% annually, whereas the ASMR remained stable overall but showed significant 2.9% annual declines during 2015 and 2021. The ASMRs in urban areas (−2.9% per year) and eastern regions (−1.5% per year) showed significant decreasing trends throughout the entire period. The mean age at death increased across all areas, and the largest increases were observed in rural areas. Deaths among people ≥65 years of age rose by 1.6%–5.6% during the entire period. Decomposition analysis indicated that the increased death counts were driven primarily by population aging (32%–43%) and population growth (8%–31%), whereas risk factors contributed negatively (−3% to −29%). Projections suggested that the number of lung cancer deaths will reach approximately 760,200 by 2030, with continued increases in the crude mortality rate but slight declines in the ASMR.

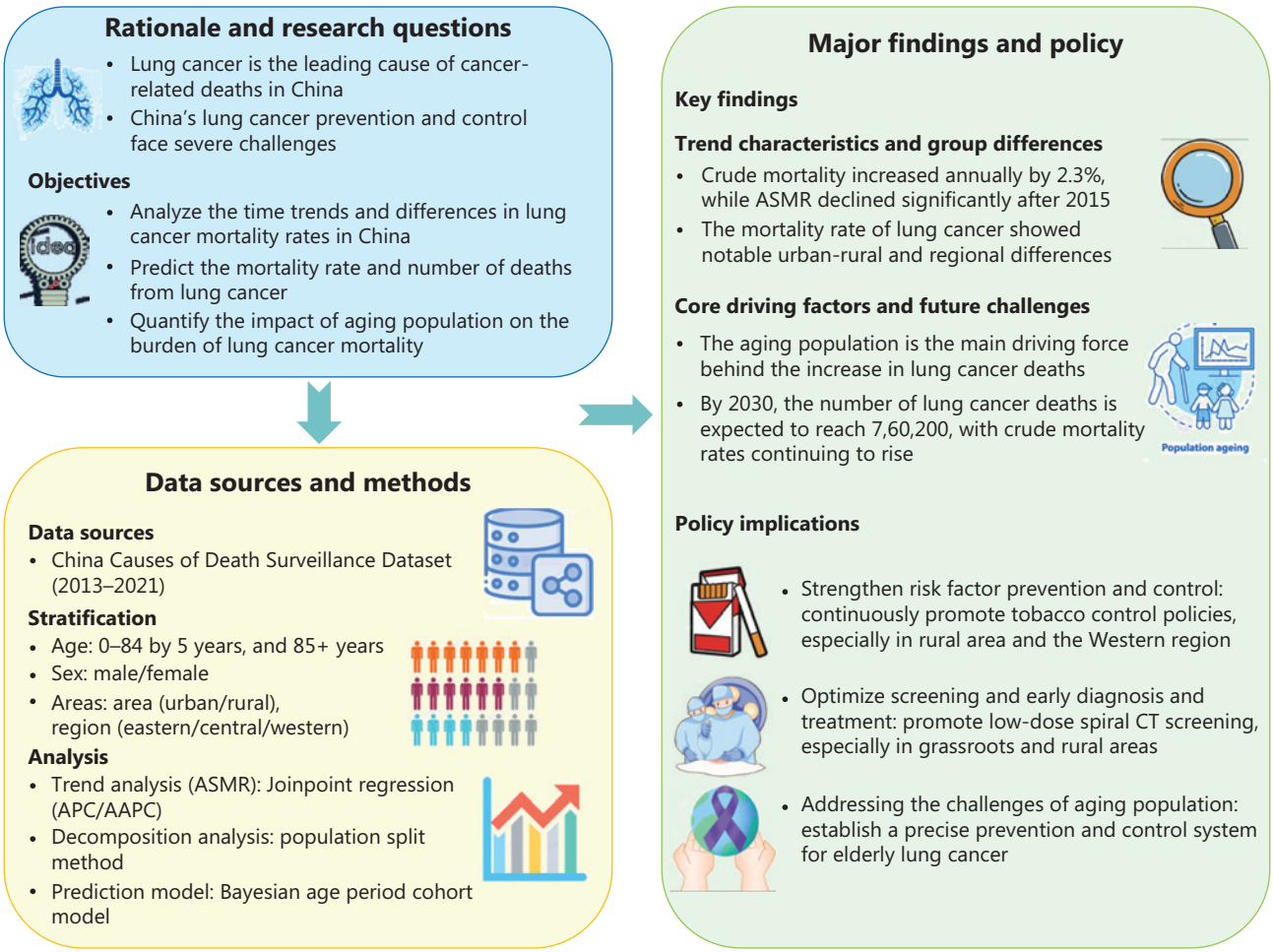
Conclusions: The lung cancer burden in China shows marked regional disparities and challenges due to population aging. To further decrease lung cancer deaths, optimized allocation of medical resources, strengthened prevention and control of lung cancer risk factors, and integration of effective policies will be required.

KEYWORDS Lung cancer; mortality; trends; 2030; China

Introduction

Lung cancer is the most common cancer threatening human health and life, as well as the leading cause of cancer-related death both worldwide and in China. According to statistics from the International Agency for Research on Cancer and National Cancer Center of China, 1.82 million new lung cancer deaths occurred worldwide in 2022, 0.73 million (40%) of which occurred in China, whose population accounts for approximately 18.3% of the global total population[1,2]. In China, lung cancer treatment poses a heavy economic burden that places great psychological pressure on patients and their families, and leads to major public health and medical resource challenges[3]. A recent study has indicated that lung cancer survival improved during 2008–2021 in China, owing to the Chinese government's national health policies for cancer prevention and control [2]. Because China accounts for one-fifth of the world's population, the global scale of cancer is strongly influenced by the cancer burden in China[4]. The age-standardized lung cancer mortality rate in China has decreased while

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Study flowchart Lung cancer mortality trends in China from 2013 to 2021, and projections to 2030. The study flowchart summarizes the rationale, methods, main findings, and policy implications of this comprehensive analysis of lung cancer mortality in China from 2013 to 2021, with projections to 2030. Data were derived from the China Causes of Death Surveillance Dataset (2013–2021), covering urban/rural and eastern/central/western regions, stratified by sex and age group. ASMRs were calculated with the Segi world standard population. Joinpoint regression was used to identify temporal trends, and Bayesian age-period-cohort models were applied to project mortality through 2030. The population split method was used to quantify contributions of population aging, population size, and risk factors to mortality changes. Crude mortality increased by 2.3% annually, whereas the ASMR significantly declined after 2015. Lung cancer mortality rates exhibited marked urban-rural and regional differences. Projections suggested that the number of lung cancer deaths will increase to 760,200 by 2030, driven primarily by the aging population. Policy implications emphasize promoting tobacco control and low-dose spiral CT screening, particularly in rural areas, and establishing a precise prevention and control system for older people with lung cancer. AAPC, average annual percentage change; APC, annual percentage chang; ASMRs, age-standardized mortality rates.

the crude mortality rate has increased, and the projected new lung cancer deaths in 2022 exceeded those in prior years; therefore, the increase in mortality has been attributed to the aging population[2,5].

China, like many other developing countries, is facing unprecedented challenges in cancer control and prevention as it undergoes rapid socioeconomic development and growth of the aging population[6]. This study reports current trends in lung cancer mortality and age at death due to lung cancer in China; the distribution of lung cancer deaths by age; and the contributions of various risk factors to deaths from 2013 to 2021. Moreover, future trends in lung cancer mortality in China through 2030 were projected, thereby extending the temporal scope and offering a coherent forward-looking perspective. These up-to-date results provide scientific evidence to potentially guide future lung cancer prevention and control efforts in China, and the management of the lung cancer burden in the context of an aging population.

Materials and methods

Data source

The recorded annual lung cancer [International Classification of Diseases, 10th Revision (ICD-10): C33–C34] death data and corresponding data on the population at risk (2.37 billion person-years) from 2013 to 2021, stratified by area (urban/rural), region (eastern/central/western), sex (male/female), and age group (0–84 years in 5 year strata, and ≥85 years), were extracted from the China Causes of Death Surveillance Dataset. This dataset summarizes the deaths and population at risk reported by 605 surveillance sites from 31 provinces (autonomous regions and municipalities). The surveillance population of >300 million people included approximately 24% of the national population until 2021. The data quality for each surveillance site was rigorously evaluated with 3 specific indicators: sex ratio, highest diagnostic institution level, and diagnostic evidence classification quality. Data with poor quality were excluded from the data summary, and a minimum mortality rate of 4.5‰ served as the standard for exclusion[7]. The details of the sampling methods and data quality control are included in "Details of data source" in **Supplementary material 1**.

Statistical analysis

Observed mortality trends in 2013–2021

The age-specific mortality rate was calculated with the aggregated number of new deaths and corresponding national population in each age group by area/region/sex. All age-standardized indicators in the text, including Age-standardized mortality rates (ASMRs) were derived through the direct method with Segi's world standard population[8]. To identify significant changes in mortality trends over time, we used Joinpoint software version 4.7.0.0 (National Cancer Institute, 2019) to estimate the annual percentage changes (APCs) and average annual percentage changes (AAPCs) of the temporal trends and their 95% Confidence Intervals (CIs) by fitting a logarithmic linear model of annual mortality rates with time as the covariate, which allowed for up to 1 joinpoint to split the time period into 2 intervals[9,10]. To identify significant changes in the trends in mean age at death over time, we calculated the mean age at death by fitting a linear regression model with year as the independent variable. The regression coefficient represented the annual change in mean age at death. To compare the distribution of deaths by age in different years, we calculated the age-standardized proportion of deaths by age. To analyze contributors to changes in the annual number of deaths, we divided lung cancer deaths according to contributions from changes in risk and changes in demographic factors, including the population size and age structure, by using the population split method described by Møller et al.[11] ("Details of method" in **Supplementary material 1 and 2**).

Predicted mortality trends from 2022 to 2030

The Bayesian age-period-cohort model[12] was fitted on the basis of the data described above, to obtain the age-specific (0–84 years in 5 year strata, and ≥85 years) APCs by area/region/sex, and was used to predict age-specific mortality rates for 2022–2030 ("Details of method" in **Supplementary material 1**). The weights of Segi's population were used to calculate the predicted ASMRs through 2030. Predicted lung cancer mortality counts were obtained by multiplying age-specific rates by population projections for the medium scenario in China obtained from the 2024 Revision of the United Nations World Population Prospects[13] in each stratum; the results were then summed to calculate the estimated national number of new deaths from 2022 to 2030. The same population split method used for the observed mortality trends was used for the predicted mortality trends. SAS software (version 9.4, SAS Institute Inc., Cary, USA) was used for statistical analysis.

Results

Observed trends in lung cancer mortality

Trends in lung cancer mortality

The trends in crude mortality rates and ASMRs for lung cancer by area/region/sex in China from 2013 to 2021 are shown in **Figure 1**, and **Tables 1 and 2**. The mortality rates were much higher in males than females for all areas/regions, and markedly varied by area/region. The crude mortality rates were higher in urban than rural areas. Mortality comparisons across regions indicated that the crude mortality rates were highest in the eastern regions, followed by the central and western regions of China. The mortality rates increased by approximately 2.3%, 3.2%, 1.5%, 3.6%, and 1.7% per year in all, rural areas, eastern, central, and western regions, respectively, but remained stable in urban areas during 2013–2021. In addition, the increases were more pronounced before than after 2015 for all, rural areas, eastern, and central regions (trend 1 *vs.* trend 2 in **Table 1**). The ASMRs in all areas/regions were lower than the crude mortality rates, and the differences in ASMR among areas/regions were smaller than those observed in crude rates. However, the ASMRs stabilized in all, rural, central, and western regions, and significantly decreased in urban areas (AAPC = −2.9%) and eastern regions (AAPC = −1.5%) during 2013–2021. Furthermore, the ASMRs showed significant decreases during 2015–2021 in all areas/regions except western regions (trend 1 *vs.* trend 2 in **Table 2**).

Trends in mean age at death due to lung cancer

The trends in mean age and age-standardized mean age at death due to lung cancer by area/region/sex in China during 2013–2021 are shown in **Tables 3 and 4**. Overall, during this period, the mean age at death due to lung cancer increased significantly in all areas/regions among both sexes. Regionally,

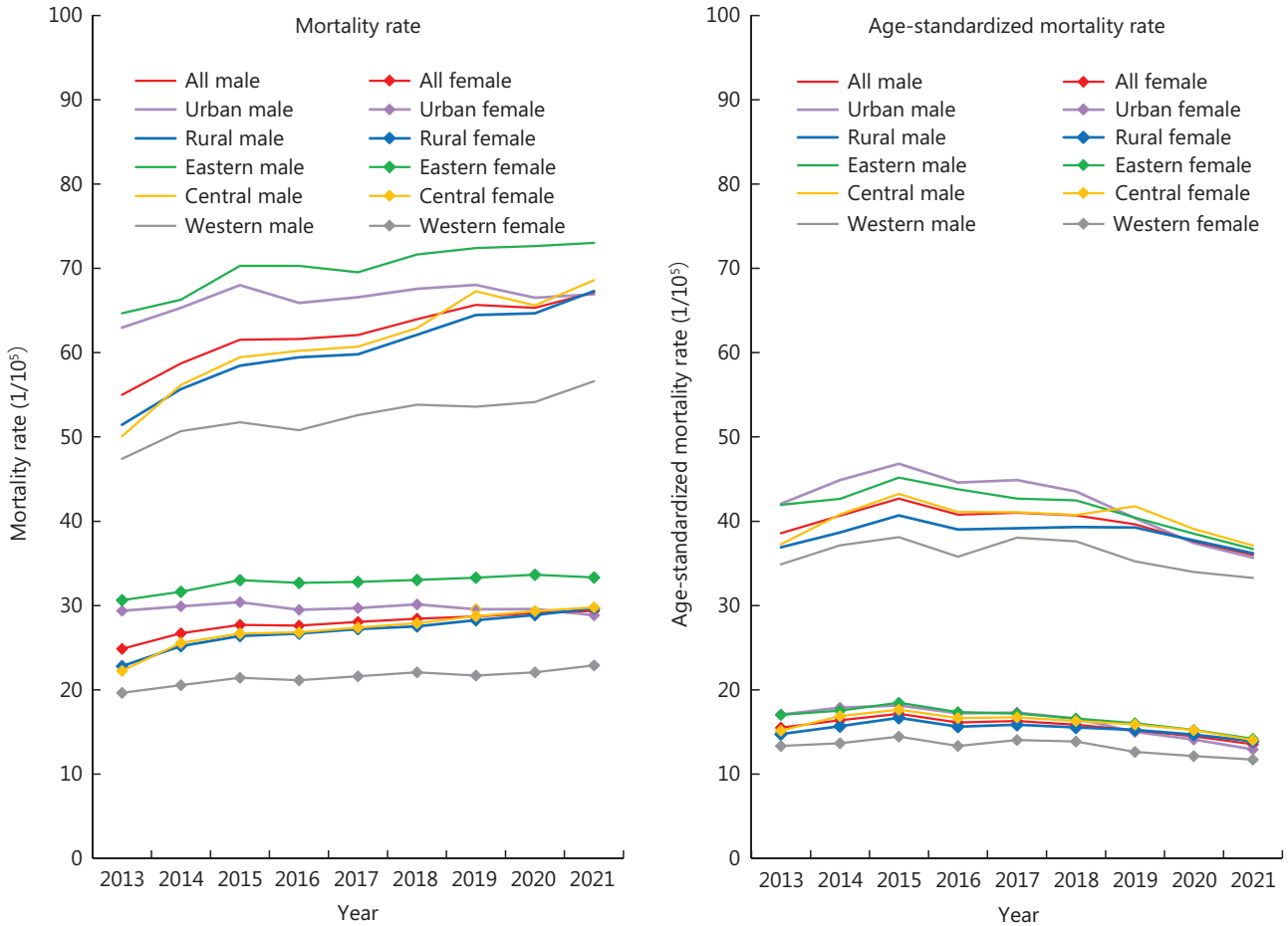


Figure 1 Trends in lung cancer mortality rates by area/region/sex in China, 2013–2021.

except in western regions, where the annual growth rate of the mean age for males and females was equal, all other areas/regions had slightly higher annual growth rates for females than males. In rural areas, the average age at death showed the fastest rate of increase, with males gaining approximately 0.27 years annually (from 67.88 to 69.95 years) and females gained approximately 0.30 years annually (from 68.88 to 71.26 years). After adjustment for the age structure of the population, the mean age at death due to lung cancer for males and females in all areas/regions still showed increasing trends each year, although the rate of increase was slower.

Changes in the distribution of lung cancer deaths by age

The changes in the distribution of lung cancer deaths by age between 2013 and 2021 are shown in **Figure 2**. The age-standardized proportions of cancer deaths in both sexes by age, for all areas/regions, showed similar patterns. The most deaths occurred in the age group of ≥60 years, which accounted for approximately 80% of all deaths. The age-standardized proportion of cancer deaths was highest in the 65–75 year age group. In general, both males and females showed a shift toward older age at death in 2021 than 2013 in most areas/regions; i.e., the proportion of deaths before the peak age group decreased, whereas that after the peak age group increased. The proportion of cancer deaths in the ≥65 year age group was greater in 2021 than 2013 in all areas/regions for both sexes, ranging from 1.62% to 5.55% (**Table S2**).

Contributors to changes in lung cancer deaths

Lung cancer mortality rates and deaths in 2013 *vs.* 2021, and the contributions of risk and demographic factors by area/region/sex to changes in lung cancer deaths are presented in **Table 5**. The crude mortality rates increased by approximately 6%–36%, whereas the ASMRs decreased by approximately 4%–18% for all areas/regions. Lung cancer deaths increased by approximately 35%–48%. Changes due to the age structure and population growth positively contributed, at rates of approximately 32%–43% and 8%–31%, respectively, whereas changes due to risk negatively contributed, at rates of approximately −3% to −29% for all areas/regions. Relatively slower increases in lung cancer deaths were observed in urban areas (35.06%) and eastern (36.46%) regions, where distinct decreases due to risk contributed approximately −29.00%

Table 1 Trends in lung cancer mortality rates by area/region/sex in China, 2013–2021

Area/region	Sex	Trend 1		Trend 2		AAPC (95% CI) (%)
		Year	APC (95% CI) (%)	Year	APC (95% CI) (%)	
All areas	Both	2013–2015	5.03* (2.41~7.74)	2015–2021	1.36* (0.89~1.75)	2.26* (1.80~2.82)
	Male	2013–2015	5.13* (1.32~9.09)	2015–2021	1.51* (0.93~2.21)	2.41* (1.74~3.18)
	Female	2013–2015	4.96* (4.08~5.76)	2015–2021	1.02* (0.90~1.17)	1.99* (1.75~2.21)
Urban areas	Both	2013–2015	2.62 (−2.13~7.49)	2015–2021	−0.22 (−0.97~0.62)	0.48 (−0.37~1.40)
	Male	2013–2015	3.20 (−1.45~8.24)	2015–2021	0.04 (−0.81~0.80)	0.76 (−0.24~1.71)
	Female	2013–2021	−0.23 (−0.70~0.24)			−0.23 (−0.70~0.24)
Rural areas	Both	2013–2015	6.14* (2.77~9.59)	2015–2021	2.18* (1.64~2.72)	3.15* (2.51~3.82)
	Male	2013–2015	5.94* (1.50~10.52)	2015–2021	2.32* (1.59~3.07)	3.22* (2.40~4.05)
	Female	2013–2015	6.84* (4.88~8.75)	2015–2021	1.86* (1.50~2.23)	3.08* (2.73~3.51)
Eastern regions	Both	2013–2015	3.83* (1.04~6.72)	2015–2021	0.68* (0.18~1.21)	1.46* (0.85~2.03)
	Male	2013–2015	3.97* (0.27~7.80)	2015–2021	0.84* (0.22~1.54)	1.61* (0.90~2.28)
	Female	2013–2015	3.41* (1.19~5.73)	2015–2021	0.37* (0.03~0.65)	1.12* (0.71~1.63)
Central regions	Both	2013–2015	8.03* (1.82~14.59)	2015–2021	2.22* (1.23~3.21)	3.64* (2.40~4.86)
	Male	2013–2015	8.04 (−0.51~17.26)	2015–2021	2.41* (0.95~3.77)	3.79* (2.05~5.49)
	Female	2013–2015	8.44* (6.80~10.08)	2015–2021	1.81* (1.61~2.14)	3.43* (3.14~3.67)
Western regions	Both	2013–2021	1.66* (1.13~2.18)			1.66* (1.13~2.18)
	Male	2013–2021	1.74* (1.09~2.32)			1.74* (1.09~2.32)
	Female	2013–2021	1.50* (0.91~2.13)			1.50* (0.91~2.13)

APC, annual percentage change; AAPC, average annual percentage change; CI, confidence interval. *APC or AAPC significantly different from 0 ($P < 0.05$).

and −19.26%, respectively, and the ASMRs in urban areas and estern regions showed more obvious decreases during 2013–2021 compared to other areas/regions (**Table 2**). These results indicated that the decreases in ASMRs might have been associated primarily with decreases in lung cancer deaths due to changes in risk.

The changes in lung cancer deaths, according to risk and demographic factors by area/region/sex, from 2013 to 2021 are shown in **Figure S1**. The numbers of lung cancer deaths by year increased for all areas/regions, peaking around 2020, then decreased thereafter. The risk-based changes increased slightly from 2013 to 2015 for most areas/regions in both sexes, but then underwent a nearly general decrease. The most rapid and pronounced declines were observed in urban areas and eastern regions. The changes due to population size and age structure also increased from 2013 to 2021 in most areas/regions, except in urban areas, where a slight decline for males and a stable trend for females in 2021 were observed. Among the changes due to demographics, the proportion of changes due to population age structure increased steadily and gradually exceeded the proportion of changes due to population size; therefore, population aging might play an increasingly important role in growing lung cancer deaths in China.

Predicted trends in lung cancer mortality

Figure 3 shows the observed and predicted trends in crude mortality rates and ASMRs for lung cancer by sex in China during 2013–2030. Similarly to the findings of the temporal trend analyses, the predicted crude mortality rates were expected to continue to increase except for a small fluctuation around 2022. The increase was expected to be more pronounced in males than females. The ASMR was predicted to continue to decrease for both sexes, but not significantly.

The predicted number of new lung cancer deaths from 2022 to 2030 in China, as well as the changes during this period, according to risk and demographic factors by sex, are listed in **Table 6**. Although the ASMRs were predicted to decrease, the new lung cancer death burden was expected to

Table 2 Trends in age-standardized lung cancer mortality rates by area/region/sex in China, 2013–2021

Area/region	Sex	Trend 1		Trend 2		AAPC (95% CI) (%)
		Year	APC (95% CI) (%)	Year	APC (95% CI) (%)	
All areas	Both	2013–2015	5.46 (−4.25~16.30)	2015–2021	−2.92* (−4.51~−1.32)	−0.89 (−2.77~0.95)
	Male	2013–2015	5.36 (−4.08~15.69)	2015–2021	−2.49* (−4.02~−0.86)	−0.58 (−2.39~1.30)
	Female	2013–2015	5.28 (−4.99~16.67)	2015–2021	−3.49* (−5.19~−1.79)	−1.37 (−3.41~0.73)
Urban areas	Both	2013–2015	1.08 (−2.46~4.75)	2015–2021	−6.75* (−9.98~−3.43)	−2.92* (−4.61~−1.24)
	Male	2013–2015	6.60 (−5.40~20.12)	2015–2021	−4.44* (−6.41~−2.52)	−1.79 (−4.09~0.63)
	Female	2013–2015	0.09 (−3.13~3.42)	2015–2021	−7.26* (−10.27~−4.16)	−3.66* (−5.20~−2.11)
Rural areas	Both	2013–2015	5.24 (−3.41~14.74)	2015–2021	−1.94* (−3.44~−0.51)	−0.20 (−1.93~1.46)
	Male	2013–2015	4.77 (−4.07~14.46)	2015–2021	−1.47* (−2.85~0.02)	0.04 (−1.72~1.82)
	Female	2013–2015	5.91 (−3.33~16.10)	2015–2021	−2.53* (−4.01~−1.04)	−0.49 (−2.31~1.27)
Eastern regions	Both	2013–2015	4.76 (−2.55~12.56)	2015–2021	−3.49* (−4.70~−2.31)	−1.49* (−2.88~−0.09)
	Male	2013–2015	4.57 (−2.39~11.95)	2015–2021	−3.19* (−4.32~−2.08)	−1.30 (−2.60~0.04)
	Female	2013–2015	4.23 (−3.92~13.14)	2015–2021	−3.87* (−5.16~−2.47)	−1.91* (−3.51~−0.32)
Central regions	Both	2013–2015	7.35 (−4.26~20.45)	2015–2021	−2.57* (−4.36~−0.59)	−0.18 (−2.38~2.12)
	Male	2013–2015	7.19 (−5.30~21.32)	2015–2021	−1.99 (−3.96~0.11)	0.23 (−2.23~2.71)
	Female	2013–2015	7.73 (−3.31~20.14)	2015–2021	−3.34* (−5.14~−1.52)	−0.68 (−2.80~1.47)
Western regions	Both	2013–2017	1.41 (−2.72~5.81)	2017–2021	−3.95 (−7.90~0.21)	−1.31 (−3.32~0.84)
	Male	2013–2017	1.60 (−2.64~5.92)	2017–2021	−3.40 (−7.41~0.72)	−0.94 (−3.01~1.23)
	Female	2013–2017	1.08 (−3.26~5.67)	2017–2021	−4.63* (−8.84~−0.33)	−1.82 (−3.99~0.41)

APC, annual percentage change; AAPC, average annual percentage change; CI, confidence interval. *APC or AAPC significantly different from 0 ($P < 0.05$).

continue to rise, to approximately 760,200 deaths (in 526,300 males and 233,800 females) due to lung cancer in China in 2030. The lung cancer deaths were predicted to increase by 16.59%, with changes due to the age structure contributing 31.52%, changes due to population size contributing −1.90%, and changes due to risk contributing −13.03%. The changes in predicted lung cancer deaths, according to risk and demographic factors by sex, from 2022 to 2030, are shown in **Figure S2**. The increase in the predicted number of new lung cancer deaths each year showed an increasing trend, with more marked increases in males than females. Mirroring the findings of the observed trend analyses, the changes due to the age structure of the population were predicted to continue to increase, whereas changes due to risk were predicted to continue to decrease, in both sexes. The changes due to population size were predicted to continue to be negative, with falling trends in both sexes in the future. These results again confirmed the findings suggesting that Chinese population aging will play an increasingly important role in the growing numbers of lung cancer deaths.

Discussion

This updated systematic analysis of lung cancer mortality trends and projections to 2030 in China was based on the most recent representative data in the China Causes of Death Surveillance Dataset. The crude lung cancer mortality rate increased by approximately 2.3% annually during 2013–2021, and the number of new lung cancer deaths in 2021 increased with respect to 2013, with a relative difference of 42.40%. As cancer prevention awareness rises, so does the number of individuals actively seeking medical attention, thus increasing lung cancer detection rates and deaths due to diagnosed lung cancer[14]. Lung cancer, the leading cause of new cancer cases and deaths in China, can be attributed to negative risk factors such as lifestyle, coal burning, air pollution, and high prevalence of smoking[15,16]. The smoking rate among the population ≥15 years of age in China was 26.6% in 2018, and a staggering 68.1% of non-smokers were exposed to second-hand smoke in public areas, a percentage far exceeding the global proportion described in the "2020 Report on Health Hazards of Smoking

Table 3 Mean age at death due to lung cancer by area/region/sex in China, 2013–2021 (in years)

Year	All areas		Urban areas		Rural areas		Eastern regions		Central regions		Western regions	
	Males	Females	Males	Females	Males	Females	Males	Females	Males	Females	Males	Females
2013	68.25	69.54	68.94	70.69	67.88	68.88	69.04	70.28	68.06	69.06	66.91	68.55
2014	68.31	69.85	69.10	71.09	67.88	69.15	69.08	70.55	68.13	69.36	67.04	68.98
2015	68.51	70.09	69.33	71.26	68.07	69.44	69.31	70.94	68.29	69.57	67.30	69.06
2016	68.69	70.29	69.45	71.60	68.27	69.56	69.43	71.02	68.59	69.63	67.35	69.76
2017	69.02	70.65	69.64	71.80	68.67	70.01	69.87	71.45	68.79	70.20	67.66	69.55
2018	69.25	71.01	69.94	72.41	68.86	70.21	70.05	71.84	68.99	70.47	68.04	70.00
2019	69.65	71.28	70.31	72.37	69.29	70.69	70.48	72.09	69.45	70.77	68.29	70.29
2020	69.81	71.43	70.40	72.52	69.48	70.83	70.67	72.11	69.58	71.11	68.45	70.44
2021	70.29	71.84	70.96	72.97	69.95	71.26	71.04	72.71	70.19	71.43	69.00	70.60
β	0.26	0.28	0.24	0.27	0.27	0.30	0.26	0.29	0.26	0.30	0.25	0.25
t	15.87	37.44	14.68	16.14	14.33	25.91	16.40	19.57	13.19	21.40	14.98	12.20
P	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

β is the annual change in mean age at death, statistically analyzed with *t*-test.

Table 4 Age-standardized mean age at death due to lung cancer by area/region/sex in China, 2013–2021 (in years)

Year	All areas		Urban areas		Rural areas		Eastern regions		Central regions		Western regions	
	Males	Females	Males	Females	Males	Females	Males	Females	Males	Females	Males	Females
2013	67.97	67.85	68.39	68.70	67.71	67.35	68.45	67.91	68.07	67.98	66.75	67.26
2014	67.86	67.93	68.64	69.16	67.40	67.28	68.36	68.06	67.95	68.00	66.69	67.43
2015	68.03	68.23	68.83	69.35	67.56	67.65	68.60	68.58	67.99	68.14	66.97	67.51
2016	67.68	67.74	68.57	69.25	67.17	66.95	68.30	67.89	67.72	67.57	66.36	67.51
2017	67.95	68.06	68.66	69.40	67.52	67.36	68.51	68.24	67.84	68.10	66.93	67.46
2018	67.85	68.09	68.68	69.67	67.35	67.25	68.35	68.30	67.71	67.99	66.97	67.61
2019	69.07	69.42	69.69	70.38	68.70	68.90	69.67	69.68	69.02	69.32	67.97	68.81
2020	69.02	69.09	69.50	70.01	68.73	68.58	69.64	69.17	68.98	69.18	67.86	68.55
2021	68.79	68.85	69.56	69.96	68.37	68.29	69.52	69.41	68.72	68.70	67.52	67.81
β	0.15	0.17	0.15	0.17	0.15	0.17	0.17	0.20	0.13	0.15	0.15	0.14
t	3.00	3.21	4.10	5.29	2.53	2.58	3.37	3.62	2.34	2.63	3.15	2.58
P	0.02	0.01	0.00	0.00	0.04	0.04	0.01	0.01	0.05	0.03	0.02	0.04

β is the annual change in age-standardized mean age at death, statistically analyzed with *t*-test.

in China" released by the National Health Commission[17]. In China, approximately 24% of male lung cancer deaths and approximately 4.8% of female lung cancer deaths are attributed to smoking[15].

We observed obvious regional disparities in lung cancer mortality rates in China. The crude lung cancer mortality rate was higher in urban than rural areas, in agreement with previous research findings[18]. This high rate is driven primarily by factors associated with intense urbanization, including air pollution, occupational exposure to industrial dust, and unhealthful diets and lifestyles[19]. However, the ASMR of lung cancer in urban areas decreased by approximately 2.9% per year

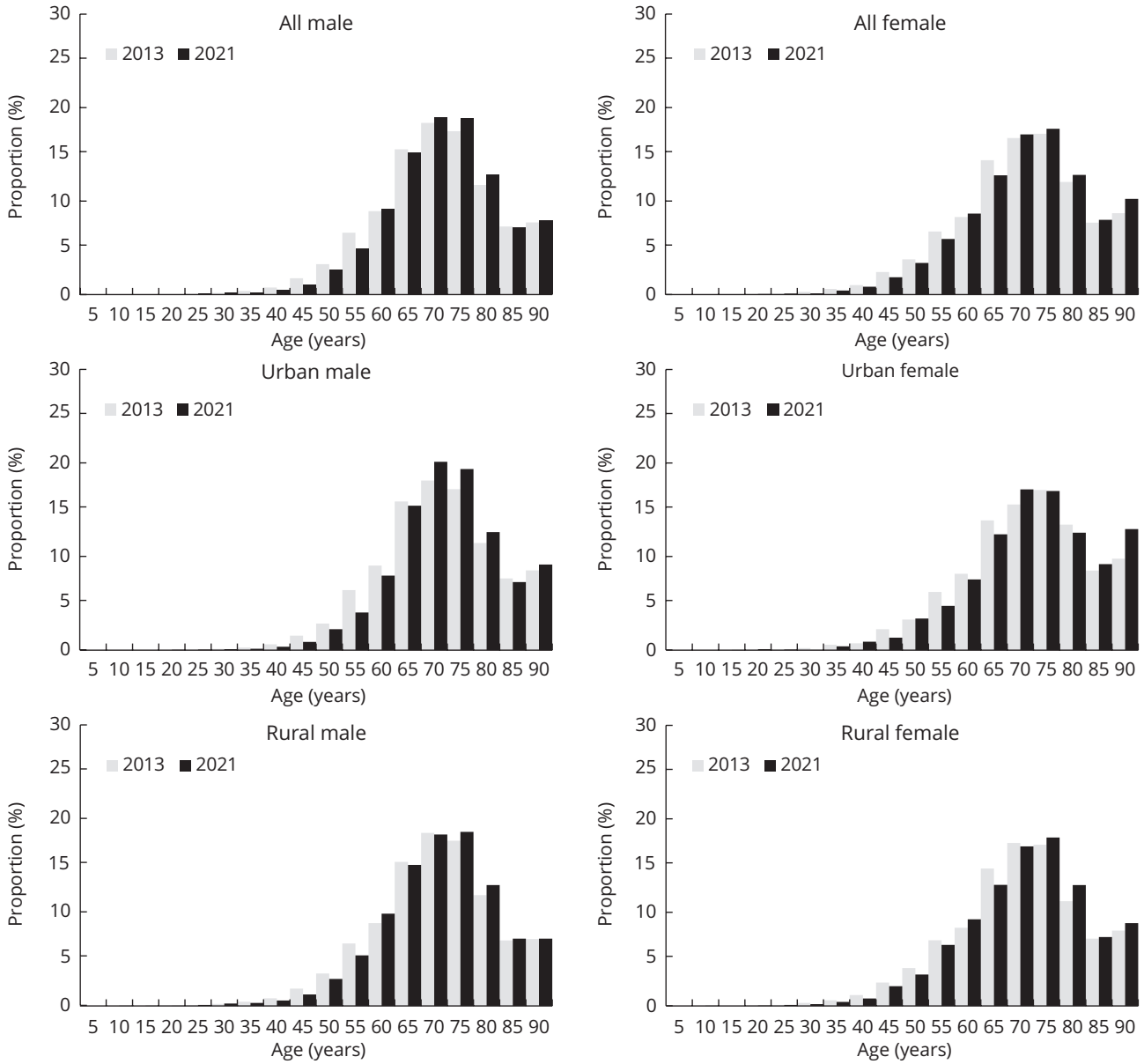


Figure 2 Continued

during 2013–2021, possibly because of the promotion of air pollution control measures, and of early lung cancer diagnosis and treatment[20,21]. Although the crude lung cancer mortality rate in rural areas was relatively low, it showed a significant increasing trend, which might have been associated with differences in smoking behavior between urban and rural areas[22]. Since the announcement of the "Healthy China 2030" initiative and the implementation of related tobacco control policies in 2016[23], 254 cities across the country have formulated and implemented smoke-free regulations. However, because residents in rural areas generally have lower levels of education than urban residents, their acceptance and cooperation with smoke control and cessation measures might be limited. This possibility is supported by studies showing an elevated attributable burden of lung cancer to smoking in economically underdeveloped provinces such as Yunnan, Guizhou, and Guangxi[15], and might explain the persistent upward trend in crude mortality in rural areas despite nationwide tobacco control efforts[24]. Meanwhile, with the advancement of industrialization in China, many enterprises have shifted from cities to rural areas, thereby increasing opportunities for rural populations to be exposed to air pollution and occupational dust[25].

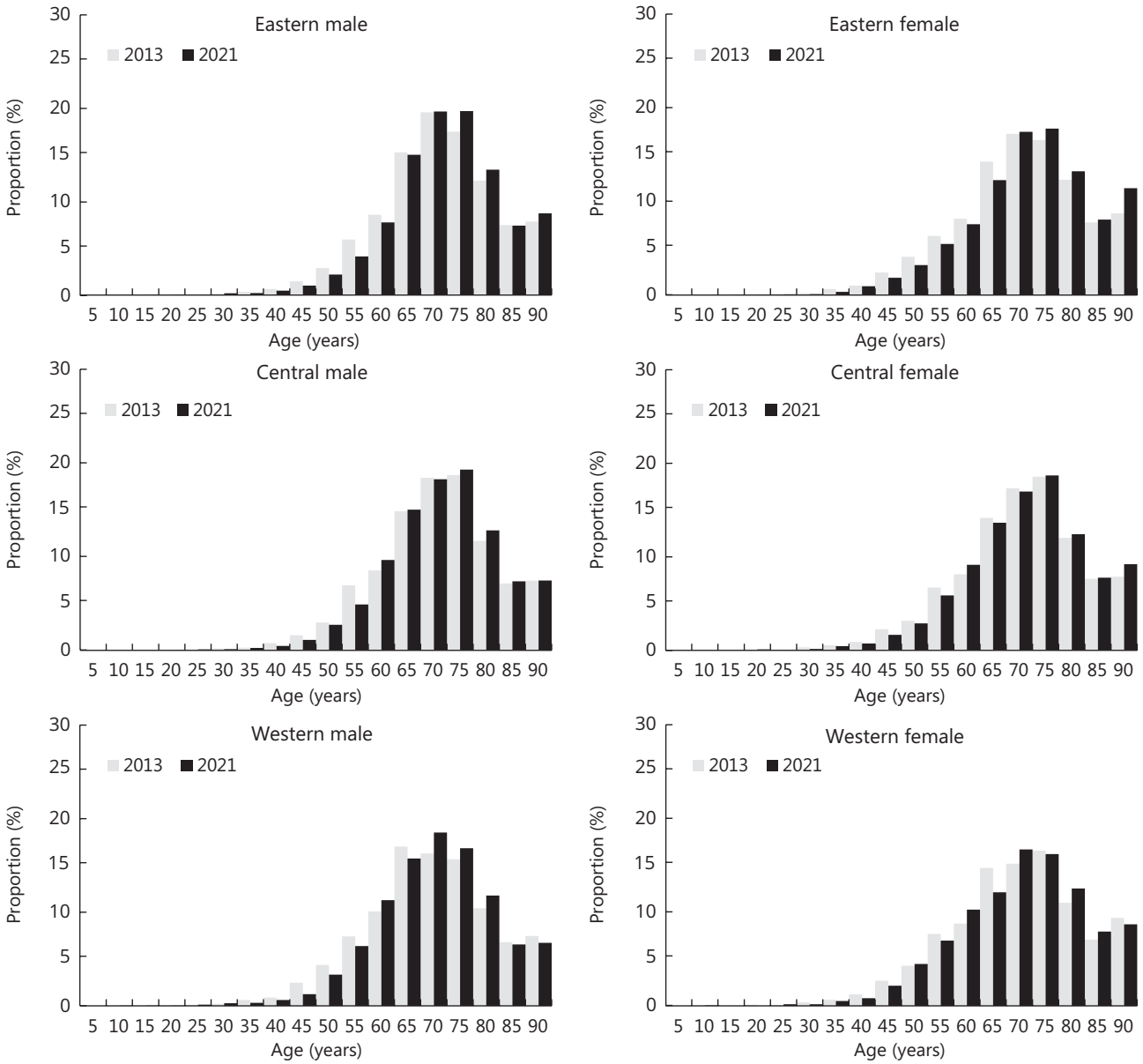


Figure 2 Age-standardized proportions of deaths by age for the indicated areas/regions/sexes in China in 2013 and 2021.

The persistent existence and dynamic changes in urban-rural differences highlight the urgency and pertinence of regional health intervention strategies.

The obvious regional differences in lung cancer mortality rates among the eastern, central, and western regions of China showed a spatial distribution pattern indicating a gradual decrease from east to west. This finding was highly consistent with the decreasing industrialization trend from east to west in China[22]. The crude lung cancer mortality rate in eastern regions was obviously higher than that in other regions; this finding was closely associated with industrial air pollution, climate conditions, and residents' energy consumption habits. On the one hand, the concentration of energy intensive industries leads to increased air pollution. As a traditional industrial center, eastern regions, particularly northeastern regions, have a high concentration of heavy industries and mineral resource development activities[26]. The continual emission of pollutants such as $PM_{2.5}$ and nitrogen oxides markedly increases the probability of respiratory system damage and gene mutations[27], thereby promoting lung cancer occurrence and development[28]. On the other hand, climate conditions and residents' energy usage patterns jointly contribute to indoor and outdoor air pollution. Because the winters in eastern provinces, including Northeast China, are prolonged and severely cold,

Table 5 Changes in lung cancer deaths in China between 2013 and 2021, according to risk and demographic factors, and area/region/sex

Area/region	Sex	2013			2021			Changes in deaths between 2013 and 2021				
		Deaths	Rate ($1/10^5$)	ASMR ($1/10^5$)	Deaths	Rate ($1/10^5$)	ASMR ($1/10^5$)	Total change (%)	Change due to risk (%)	Changes due to demographics		
										Total (%)	Age structure (%)	Population size (%)
All areas	Both	91,380	40.21	26.74	130,121	48.57	24.34	42.40	−12.10	54.49	36.60	17.89
	Male	63,673	55.00	38.59	91,378	67.17	35.99	43.51	−8.99	52.50	34.99	17.51
	Female	27,707	24.86	15.52	38,743	29.38	13.55	39.83	−16.94	56.77	38.48	18.29
Urban areas	Both	32,617	46.40	29.12	44,052	48.00	23.74	35.06	−29.00	64.06	33.52	30.54
	Male	22,422	62.98	42.06	30,908	66.92	35.67	37.85	−24.04	61.88	32.16	29.72
	Female	10,195	29.38	17.07	13,144	28.84	12.94	28.93	−37.31	66.24	34.87	31.37
Rural areas	Both	58,763	37.44	25.58	86,069	48.87	24.68	46.47	−3.28	49.74	37.52	12.23
	Male	41,251	51.45	36.91	60,470	67.30	36.21	46.59	−1.34	47.93	35.85	12.08
	Female	17,512	22.81	14.75	25,599	29.67	13.89	46.18	−5.77	51.95	39.57	12.38
Eastern regions	Both	41,986	47.87	28.91	57,294	53.44	24.94	36.46	−19.26	55.72	33.48	22.24
	Male	28,720	64.68	41.96	39,665	73.01	36.70	38.11	−18.56	56.67	34.33	22.34
	Female	13,266	30.63	17.03	17,629	33.33	14.19	32.89	−21.86	54.75	32.60	22.15
Central regions	Both	30,060	36.46	26.04	44,353	49.47	25.12	47.55	−4.03	51.58	42.83	8.75
	Male	21,089	50.06	37.26	31,195	68.61	37.12	47.92	0.61	47.31	39.38	7.93
	Female	8,971	22.25	15.15	13,158	29.78	14.04	46.67	−9.47	56.14	46.54	9.60
Western regions	Both	19,334	33.87	24.03	28,474	40.09	22.23	47.27	−9.39	56.66	32.25	24.42
	Male	13,864	47.41	34.89	20,518	56.60	33.28	47.99	−5.00	52.99	29.03	23.96
	Female	5,470	19.65	13.32	7,956	22.88	11.73	45.45	−16.22	61.67	36.78	24.89

ASMR is the age-standardized mortality rate with Segi's world standard population.

residents heavily rely on coal for heating and cooking[29]. They usually keep their doors and windows closed to retain indoor warmth, thus leading to inadequate ventilation. Harmful substances emitted from indoor coal combustion combined with outdoor industrial pollution create a compound exposure effect, which can further impair lung health[30]. The trend analysis indicated that although the crude mortality rate continued to increase in the eastern, central, and western regions from 2013 to 2021, the ASMRs showed a relatively stable trend in the central and western regions, but a downward trend in the eastern regions. These findings might have been because the eastern regions have more professional physicians and comprehensive hospitals[31]. This difference in medical resources also suggested a potential for numerous undetected or misdiagnosed cases of lung cancer in remote areas of the central and western regions; consequently, the actual disease burden might have been underestimated. Therefore, environmental pollution exposure during the industrialization process is a

Table 6 Predicted number of new lung cancer deaths from 2022 until 2030 in China and changes between 2022 and 2030 apportioned into changes due to risk and demographics by sex

Sex	Number of estimated deaths (95% CI) ($1/10^4$)								Changes in deaths between 2022 and 2030 (%)				
	2022	2023	2024	2025	2026	2027	2028	2029	2030	Total change	Change due to risk	Changes due to demographics	
												Total	Age structure	Population size
Both	65.20	66.60	67.83	69.01	70.18	71.50	73.13	74.67	76.02	16.59	−13.03	29.63	31.52	−1.90
	(56.72~75.30)	(57.52~77.61)	(58.27~79.00)	(58.80~80.94)	(59.60~83.20)	(60.35~84.90)	(61.47~87.32)	(61.98~89.94)	(62.95~92.03)					
Male	44.83	45.84	46.72	47.57	48.41	49.35	50.54	51.66	52.63	17.39	−11.11	28.50	30.91	−2.40
	(39.57~50.88)	(40.25~52.47)	(40.85~53.40)	(41.26~54.77)	(41.87~56.30)	(42.50~57.53)	(43.26~59.12)	(43.73~61.07)	(44.51~62.34)					
Female	20.36	20.76	21.11	21.44	21.77	22.14	22.59	23.01	23.38	14.84	−16.59	31.43	32.8	−1.37
	(17.15~24.42)	(17.27~25.14)	(17.43~25.60)	(17.53~26.17)	(17.73~26.90)	(17.85~27.37)	(18.21~28.20)	(18.25~28.87)	(18.44~29.69)					

CI, confidence interval.

driving factor affecting lung cancer mortality rates, and uneven distribution of medical resources also influences regional patterns of lung cancer mortality rates.

The ASMR of lung cancer decreased more in females than males from 2015 to 2021, particularly in urban areas, and the average age of death was generally higher in females than males. These phenomena might have been due to a combination of factors. On the one hand, smoking is the most important negative risk factor for lung cancer. The smoking rate among Chinese males has long been markedly higher than that in females[32], thus resulting in a relatively high baseline of lung cancer mortality in males and a comparatively slow decline in this rate under the influence of tobacco control policies. In recent years, the gradual promotion of air quality management in urban and rural areas and smoking bans in public places have had relatively limited effects on lung cancer mortality among males, given their high initial level of exposure. Therefore, the protective effects might be more pronounced among females. On the other hand, women in China have longer life expectancies than men[13,33], and the incidence rate of lung cancer increases with age. Therefore, because a larger proportion of women than men develop the disease at older ages, the average ages at onset and death are naturally elevated. Previous research has indicated that female patients with lung cancer in China have a higher overall survival rate than male patients[34,35] and show faster improvement in the 5-year survival rate. Consequently, female patients tend to survive longer after diagnosis, thereby further increasing the average age of death. In summary, the sex disparity in lung cancer mortality not only reflects the concentrated effects of negative risk factors such as smoking in males, but also indicates the lifespan and survival group characteristics among females.

The trend analysis of overall lung cancer mortality revealed that, from 2013 to 2015, the crude mortality rate and ASMR for lung cancer in most areas/regions increased, particularly in rural areas. However, after 2015, the growth rate of the crude mortality rate significantly slowed, and the ASMR reversed from an increase to a decrease, particularly in urban areas. This trend shift indicated that 2015 was a critical turning point in China's lung cancer mortality rate, coinciding with the preparation and initial effectiveness of several critical newly launched national policies. First, in public health, the "Healthy China 2030" planning outline, officially released in 2016, had its pilot and policy preparation work initiated as early as 2015[23]. This strategy prioritized the prevention and control of chronic diseases, and explicitly proposed strengthening early cancer screening and diagnosis, particularly in urban and high-risk areas, and vigorously promoting lung cancer screening, thereby markedly improving the proportions of early diagnosis and treatment of lung cancer cases. The implementation of low-dose computed tomography screening in urban and high-risk areas in 2016 has been identified as a key strategy to decrease lung cancer mortality

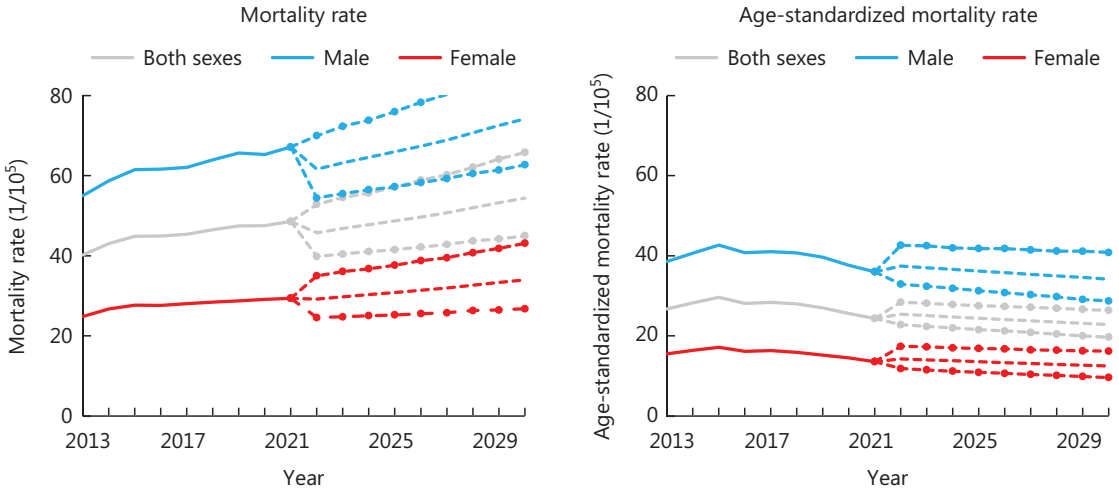


Figure 3 Observed (solid lines) and predicted (dashed lines) trends and 95% confidence intervals (dashed lines with spots) in lung cancer mortality rates by sex in China, 2013–2021.

through early detection, as outlined in planning studies for the Chinese context[21]. These aspects probably contributed to the more significant decline in ASMR observed in urban areas after 2015. Second, in environmental governance, the preliminary effect of the "Measures for Air Pollution Prevention and Control" implemented in 2013 began to take shape in 2015[36] and led to a marked decrease in the concentration of inhalable particulate matter. This improvement in air quality has been directly associated with decreased lung cancer mortality and improved survival in Chinese populations, as evidenced by empirical studies conducted in high-exposure areas such as Beijing[20]. Furthermore, the continued improvement in the medical security system has also provided important support for decreasing the lung cancer mortality rate. In 2015, the State Council issued the "Opinions on the Comprehensive Implementation of Major Illness Insurance for Urban and Rural Residents", which essentially achieved full major illness insurance coverage and markedly improved treatment accessibility and medication adherence among patients with lung cancer[37]. Notably, the uneven development across regions remains an important factor affecting policy effectiveness. Rural areas, compared with urban areas, are limited by scarcer medical resources and slower implementation of environmental policies, resulting in insignificant decline in ASMR from 2013 to 2021 and reflecting marked regional differences in policy implementation. In the future, resource investment and policy implementation must be further strengthened in rural areas to achieve overall improvements in the effectiveness of lung cancer prevention and control nationwide.

The observed lung cancer ASMR trend from 2013 to 2021 was consistent with the long-term decreasing trend from 2000 to 2018, according to the national cancer registry data report. However, the trend was not significant, and differences were observed in short-term fluctuation patterns, potentially because of differences in data sources. The cancer registration data came from 22 consecutive cancer registration offices covering 3.34% of the Chinese population[2]. These surveillance sites are located in regions with high cancer incidence rates or in eastern economically developed areas, where cancer registration systems were established relatively earlier, cover larger populations, and operate with more mature registration mechanisms and quality management protocols. Whether these cancer registries are nationally representative remains to be assessed[38]. The China Cause of Death Surveillance Dataset in this study covers multiple surveillance sites in both rural and urban areas, and has broader representativeness in terms of geographical distribution and population structure. The ASMR in urban areas significantly decreased while the ASMR in rural areas tended to stabilize, thus further indicating the insignificant trend in the national ASMR decline in this study. Moreover, from 2015 to 2021, the ASMR of lung cancer in China significantly decreased, by approximately 2.9% per year. Despite variations in the AAPC values, both datasets demonstrated a consistent overall declining trend in the past decade. The Chinese government initiated a series of cancer control programs in both rural and urban areas in 2005, which have made achievements in China in recent decades. Given that screening can promote early detection and diagnosis, and enhance awareness of cancer prevention and control, more lung cancer cases and deaths could be prevented by increasing screening coverage[14]. The observed decreases in ASMRs might have been associated primarily with decreases in lung cancer deaths due to cancer risk control and management efforts.

The increase in crude mortality and decrease in ASMR might be partly attributable to the growth and aging of the Chinese population, which are recognized negative risk

factors for lung cancer[39,40]. The Chinese population expansion in recent decades has contributed to the growing lung cancer burden[41]. According to the World Population Prospects 2024, the proportion of older people in China continues to rise, and projections suggest that >500 million people will be ≥60 years of age by 2050[13]. The mortality rates by birth cohort increased in older people but decreased in younger people, according to a previous study. In addition, older populations are associated with higher lung cancer mortality rates in China[39]. Together, these aspects might explain why our study indicated a shift toward older age at death due to lung cancer in 2021 *vs.* 2013. As the aging of the population increases, the number of lung cancer deaths may rise, and the mean age at death may also increase. Therefore, the increases in crude mortality rate and mean age at death in China might be due primarily to the Chinese population aging.

According to cancer mortality predictions, by 2030, lung cancer in China is expected to lead to both an increase in the crude mortality rate and a slow decline in the ASMR. Therefore, our findings indicated that, after exclusion of the effects of age structure, the actual lung cancer mortality rate has been controlled to a certain extent. However, the magnitude of the decline has not been marked. Although the ASMR is expected to decrease, the actual number of deaths will continue to rise, because of China's large population base and aging population structure. The total number of lung cancer deaths was estimated to reach 760,000 by 2030, and this mortality burden is expected to be more prominent among the male population. Consequently, although the negative risk factors for lung cancer have been controlled, their effects have not yet offset the effects of changes in age structure.

To address the challenge of an aging population, promotion of tobacco control policies, popularization of low-cost early screening, and strengthening of grassroots diagnosis and treatment capabilities are recommended. As the population ages, additional recommendations include establishing a precision prevention and control system for lung cancer in older people; conducting regular low-dose spiral CT screening with artificial intelligence (AI)-aided interpretation to decrease false positives; deploying mobile screening vehicles in communities; and organizing nursing staff or family physician visits for health surveillance and management among disabled older people. Simultaneously, smoking cessation programs should be promoted, which allow older people to redeem home care vouchers for each completed smoking cessation course or physical exercise, financed through cost sharing between medical insurance and tobacco taxes. Simultaneously, by leveraging smart healthcare and care platforms for older people, personalized protective knowledge can be disseminated to achieve active early warning and precise interventions for lung cancer prevention and control.

This study based on the China Causes of Death Surveillance Dataset, which analyzed lung cancer mortality trends, quantified the effects of population aging on changes in mortality burden, and projected future trends to 2030, has several strengths and limitations. The major strength of this study is its use of high-quality and nationally representative data, covering a total population of approximately 2.37 billion person-years from 2013 to 2021. Since 2013, the surveillance system has expanded to 605 sites with ≥300 million people, accounting for approximately 24% of China's population, thus enhancing representativeness at both national and provincial levels. Although minor adjustments were made to the included sites across years, because of data quality differences among different years, the dataset reliably reflects overall trends in lung cancer mortality in China during this period[42]. However, because the study was limited to the acquired data sources, we were able to discuss only the contributions of related risk factors to the death burden from the perspective of data segmentation but could not quantify the contributions of different risk factors to changes in lung cancer deaths. This aspect will require further in-depth investigation in future studies.

Conclusions

In summary, this analysis based on the China Causes of Death Surveillance examined current trends in lung cancer mortality and projected future trends in China through 2030. The effects of the population age structure on the burden of lung cancer deaths in China were quantified to better understand the influence of population aging on changes in lung cancer burden. With changes in the population age structure in China, the future lung cancer burden is expected to continue to rise, thus posing further challenges in lung cancer prevention and control.

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Conflict of interest statement

No potential conflicts of interest are disclosed.

Author contributions

Conceived and designed the analysis: Xiaoqiu Dai, Xin Liang.
Collected the data: Xin Liang, Xiang Li, Yifei Yao.
Contributed data or analysis tools: Xin Liang, Yifei Yao.
Performed the analysis: Xin Liang, Xiang Li.
Wrote the paper: Xin Liang, Xiang Li.

Data availability statement

All data used in this study are publicly available from the China Causes of Death Surveillance Dataset published by the National Center for Chronic and Noncommunicable Disease Control and Prevention (https://ncncd.chinacdc.cn/jcysj/siyinjcx/syfxbg/).

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