



Original Article

Burden Profile, Temporal Trends, and Projections of Bladder Cancer in China: A Systematic Study Based on the Global Burden of Disease Study 2023



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Abstract

Background and objectives: Bladder cancer (BC) remains a major public health concern in China, but comprehensive and up-to-date assessments of its burden and temporal patterns remain limited. This study aimed to systematically evaluate the current burden, temporal trends, and future projections of BC in China using data from the Global Burden of Disease Study 2023.

Methods: Data on BC incidence, mortality, disability-adjusted life years, and risk-attributable mortality in China from 1990 to 2023 were extracted from the Global Burden of Disease Study 2023. Temporal trends were assessed using Joinpoint regression, with a maximum of six joinpoints allowed, to estimate annual percentage changes and average annual percentage changes. Age-period-cohort models based on log-linear Poisson regression were used to examine age, period, and cohort effects. Bayesian age-period-cohort models were then applied to project incidence and mortality rates to 2030 while accounting for age-period-cohort effects and demographic changes.

Results: From 1990 to 2023, crude incidence, mortality, and disability-adjusted life year rates increased, whereas age-standardized rates generally declined (average annual percentage changes = −0.32%, −1.31%, and −1.62%, respectively). Recent upward trends were nevertheless observed across all three indicators, particularly for incidence and mortality during 2020–2023 (annual percentage changes = 5.05% and 4.39%, respectively). Local drifts were negative in most age groups but approached or exceeded zero in the oldest groups. The incidence local drift was 0.35% (95% confidence interval [CI]: −0.07%, 0.78%) in the 85–89-year age group and 0.64% (95% CI: −0.31%, 1.61%) in the 90–94-year age group, whereas the corresponding mortality local drifts were −0.70% (95% CI: −0.97%, −0.43%) and −0.18% (95% CI: −0.72%, 0.36%), respectively. Compared with the

reference period (2004–2008), the relative risks for incidence and mortality in 2019–2023 were 0.95 (95% CI: 0.91–0.98) and 0.75 (95% CI: 0.71–0.78), respectively. Compared with the reference cohort (1951–1956), earlier birth cohorts had elevated risks; in the 1901–1906 cohort, the relative risks were 1.13 (95% CI: 0.82, 1.57) for incidence and 2.10 (95% CI: 1.75, 2.52) for mortality. During 2024–2030, both crude incidence and crude mortality rates were projected to increase further.

Keywords: Bladder cancer; Disease burden; Temporal trends; Age-period-cohort analysis; China; Global Burden of Disease Study 2023.

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Conclusions: Despite long-term declines in age-standardized rates, BC remains a substantial burden in China, and re-

cent upward trends warrant attention. These findings support targeted primary prevention and risk-stratified early-detection strategies for high-risk populations.

Introduction

Bladder cancer (BC) is one of the most common malignancies of the urinary system worldwide. According to GLOBOCAN 2022, BC ranked ninth for cancer incidence and thirteenth for cancer mortality globally, with an estimated 614,298 new cases and 220,596 deaths in 2022, indicating a substantial global health burden.¹ BC is also characterized by a high risk of recurrence, with reported recurrence rates ranging from 50% to 70%; therefore, many patients require prolonged, and sometimes lifelong, surveillance because of persistent risks of recurrence and progression.² Previous studies have further shown that BC has one of the highest lifetime treatment costs per patient among all cancers, placing considerable demands on health-care systems and substantial economic and psychological burdens on patients.³

China bears a particularly large burden of BC, with the highest numbers of incident cases and deaths worldwide, accounting for approximately 15% of global incident cases and 19% of global deaths.⁴ BC occurs predominantly in older adults,⁵ and several modifiable risk factors, including tobacco use and metabolic conditions such as diabetes mellitus, contribute to its development and progression.^{6,7} In the context of population aging and changing patterns of modifiable risk exposure,^{8,9} a clearer understanding of the current burden, temporal trends, and potential drivers of BC is essential for guiding prevention and control strategies. Therefore, using data from the Global Burden of Disease (GBD) Study 2023, this study systematically assessed the burden of BC in China by characterizing its current burden profile, temporal trends, age-period-cohort patterns, and future projections. Incidence, mortality, and disability-adjusted life years (DALYs) were used as the main burden indicators. Because population-based organized screening for BC is not currently available in China, and targeted prevention and early-detection strategies are increasingly needed, this study also aimed to identify high-risk age groups and quantify the contributions of modifiable risk factors to inform future risk-stratified screening, early detection, and primary prevention strategies.

Materials and methods

Data sources

Data were obtained from the GBD 2023 Study, coordinated by the Institute for Health Metrics and Evaluation, which provides annually updated and internally comparable estimates of health loss for 375 diseases and injuries and 88 modifiable risk factors across 204 countries and territories.¹⁰ For this analysis, bladder cancer burden estimates for China were extracted from the GBD 2023 results platform, including incidence, mortality, DALYs, years of life lost, and years lived with disability, together with corresponding crude, age-specific, and age-standardized rates per 100,000 population. The GBD estimates of disease burden in China were based on multiple nationally representative data sources.¹¹ Mortality data were primarily derived from the Disease Surveillance Points system, the National Maternal and Child Surveillance System, national censuses and surveys, the China Cancer Registry, the Chinese Center for Disease Control and Prevention cause-of-death reporting system, mortality data from the Macao Special Administrative Region (SAR) and Hong Kong SAR, and published studies and reports.

Data for non-fatal outcomes were mainly obtained from the China Cancer Registry, national surveys, hospital inpatient records, the Chinese Center for Disease Control and Prevention cause-of-death reporting system, and relevant published literature.¹¹ GBD 2023 used unified analytical frameworks and standardized modelling tools to improve comparability and internal consistency of estimates across regions and over time. Non-fatal outcomes were synthesized and modelled using DisMod-MR 2.1, a Bayesian meta-regression tool that ensures internal consistency across epidemiological parameters by age, sex, year, and location. Cause-specific mortality was estimated using the Cause of Death Ensemble model, an ensemble modelling framework that evaluates multiple plausible statistical models and covariates and combines them to generate robust and internally consistent mortality estimates across locations and time.¹² DALYs were calculated as the sum of years of life lost and years lived with disability. Age-standardized rates were computed using the GBD reference population to facilitate comparisons across populations and over time. GBD 2023 reports uncertainty using 95% uncertainty intervals, defined by the 2.5th and 97.5th percentiles of 250 posterior draws.¹⁰ These uncertainty estimates partly account for heterogeneity and incompleteness in the underlying data sources, as well as uncertainty introduced during the modelling process.

Estimation of bladder cancer burden attributable to risk factors

GBD 2023 provides standardized estimates of exposure levels, relative risks, and attributable disease burden for 88 modifiable risk factors across 204 countries and territories.¹⁰ Risk-outcome pairs included in the estimation met the World Cancer Research Fund criteria for convincing or probable evidence, beginning with GBD 2010. Additional risk factors were incorporated according to the Burden of Proof Risk Function.¹⁰ Attributable burden was estimated using the comparative risk assessment approach. In this framework, the population attributable fraction was calculated to quantify the proportion of disease burden that could be avoided if exposure to a given risk factor were reduced to its theoretical minimum risk exposure level. Attributable deaths and DALYs were then derived by applying the corresponding population attributable fractions to total deaths and DALYs.

Statistical analysis

Trend analysis

Joinpoint regression analysis was used to quantify temporal trends in bladder cancer burden over time. This method identifies time points at which statistically significant changes in trend occur and fits a series of log-linear regression models to estimate annual percentage changes (APCs) for each segment.¹³ Given the long study period (1990–2023), the maximum number of joinpoints was set to six to allow sufficient flexibility for detecting potential changes in temporal trends.¹⁴ Model selection was based on the weighted Bayesian information criterion, which balances model fit and complexity by penalizing excessive numbers of joinpoints and thereby reducing the risk of overfitting.¹⁵ The final model was the most parsimonious model with the optimal weighted Bayesian information criterion value. The average annual percent change (AAPC) was calculated to summarize the overall trend across the full study

period, weighted by the length of each segment. A positive AAPC with a positive lower bound of the 95% confidence interval (CI) indicates a statistically significant increasing trend in the age-standardized rate, whereas a negative AAPC with a negative upper bound of the 95% CI indicates a statistically significant decreasing trend. Statistical significance was evaluated using Monte Carlo permutation tests. Sensitivity analyses were conducted for the Joinpoint regression models. First, the maximum number of joinpoints was varied. The main analysis allowed up to six joinpoints, and alternative models allowing up to four and five joinpoints were fitted using the same input data and model settings. The numbers of selected joinpoints, AAPCs, and recent APC segments were compared across specifications. Second, to examine the influence of the COVID-19 pandemic and the immediate post-transition period on observed temporal trends, the Joinpoint analyses were repeated after excluding data from 2020 to 2023. AAPCs and APC segments estimated after this exclusion were then reported.

Age-period-cohort effect analysis

An age-period-cohort model was used to disentangle the effects of age, period, and birth cohort on bladder cancer incidence and mortality.¹⁶ Age effects represent changes in risk associated with biological aging and different stages of the life course. Period effects reflect influences occurring at specific calendar times, such as advances in medical care, implementation of public health policies, or broader environmental changes that affect all age groups simultaneously. Cohort effects capture risk differences across groups born in the same period, potentially reflecting shared early-life exposures or common social and environmental experiences. In general, the age-period-cohort model fits a log-linear Poisson regression framework:

$$\log(Y_i) = \mu + \alpha * \text{age}_i + \beta * \text{period}_i + \gamma * \text{cohort}_i + \varepsilon_i$$

where Y_i denotes the crude rate for incidence, mortality, or DALYs; μ is the intercept; α , β , and γ are the regression coefficients for age, period, and cohort, respectively; and ε is the error term. To address the inherent linear dependency among age, period, and cohort, APC analysis was conducted using the estimable-function framework.¹⁷ This approach focuses on identifiable estimable functions rather than attempting to separately estimate the non-identifiable linear components of age, period, and cohort effects, and it avoids arbitrary reference-category constraints for the reported summary measures. Within this framework, interpretable parameters were derived, including net drift (overall annual percentage change), local drift (age-specific annual percentage change), longitudinal age curves, and period and cohort relative risks (RRs). These measures enable a comprehensive assessment of temporal dynamics and underlying epidemiological patterns in disease burden. The APC model was fitted using weighted least squares, assuming that the count data followed a Poisson distribution with allowance for extra-Poisson variation. Methodological details have been described previously.¹⁸ Because APC estimates may be influenced by the specification of age and period intervals, which also determines the corresponding birth-cohort categories, sensitivity analysis was conducted by aggregating the original five-year age groups and five-year periods into 10-year age groups and 10-year periods.

Burden projection

Short-term projections of bladder cancer burden in China to 2030 were generated using the Bayesian age-period-cohort (BAPC) model, which is well suited to complex, high-dimensional, and sparse data frequently encountered in large-scale epidemiologi-

cal studies.¹⁹ The BAPC model extends the traditional generalized linear model framework within a Bayesian context. Model estimation was performed using integrated nested Laplace approximation, which provides efficient Bayesian inference without relying on computationally intensive Markov chain Monte Carlo methods.²⁰ BAPC models have been widely applied in epidemiological research, particularly in studies involving age-structured population data and complex cohort effects. In this study, BAPC models were used to project both age-standardized and crude rates of bladder cancer incidence and mortality. Sensitivity analysis was also conducted by fitting an alternative BAPC model with stronger smoothing priors. Specifically, the log-gamma hyperparameters for the RW2 priors of the age, period, and cohort effects were changed from shape = 1 and rate = 5×10^{-5} in the main model to shape = 1 and rate = 5×10^{-6} in the alternative model, while the overdispersion prior was kept unchanged.

Data processing and visualization

Temporal trend analyses were conducted using the Joinpoint Regression Program (version 5.4.0). Data processing, statistical analyses, and visualization were performed in R software (version 4.4.3). A two-sided P value < 0.05 was considered statistically significant.

Results

Profiles of BC burden in China, 2023

Table 1 presents the burden profile of bladder cancer in China in 2023 for the overall population and by sex. An estimated 105,632 incident cases and 44,728 deaths from bladder cancer occurred in China in 2023, corresponding to a crude incidence rate of 7.38 per 100,000 and a crude mortality rate of 3.13 per 100,000. The age-standardized incidence rate (ASIR) and age-standardized mortality rate (ASMR) were 4.66 and 2.00 per 100,000, respectively. Bladder cancer accounted for 902,946 DALYs, with a crude DALY rate of 63.11 per 100,000 and an age-standardized DALY rate (ASDR) of 39.67 per 100,000. A marked sex disparity was observed across all burden indicators. Males accounted for most incident cases, deaths, and DALYs, with 85,985 new cases, 34,936 deaths, and 719,427 DALYs, compared with 19,647 cases, 9,793 deaths, and 183,520 DALYs in females. Age-standardized rates were consistently higher in males than in females: the ASIR was nearly five times higher (7.98 vs. 1.66 per 100,000), the ASMR was more than four times higher (3.42 vs. 0.81 per 100,000), and the ASDR was also substantially higher (66.57 vs. 15.45 per 100,000). Among modifiable risk factors, tobacco exposure was the leading contributor to bladder cancer deaths in China. Overall, 38.06% of bladder cancer deaths were attributable to smoking, with a substantially higher proportion in males than in females (46.60% vs. 7.62%). By contrast, the proportion of deaths attributable to high fasting plasma glucose (FPG) was lower overall (10.37%) and showed only a small sex difference, accounting for 10.42% of deaths in males and 10.22% in females.

Temporal trends of BC burden in China, 1990 to 2023

Figure 1 and Supplementary Table 1 present temporal trends in the incidence, mortality, and DALY burden of bladder cancer in China from 1990 to 2023. The crude incidence rate showed a significant overall upward trend, with an average annual increase of 2.18% (95% CI: 2.05% to 2.32%, $P < 0.001$). In contrast, the ASIR showed a slight but significant overall decline during the same pe-

Table 1. Burden profile of bladder cancer in China, 2023

Level	Incidence			Mortality			DALY			Risk factor	
	Number	CIR	ASIR	Number	CMR	ASMR	Number	CDR	ASDR	Percentage of deaths attributable to tobacco	Percentage of deaths attributable to high FPG
Overall	105,632 (85,504, 126,385)	7.38 (5.98, 8.83)	4.66 (3.78, 5.54)	44,728 (38,358, 50,790)	3.13 (2.68, 3.55)	2.00 (1.71, 2.28)	902,946 (783,966, 1,020,874)	63.11 (54.80, 71.36)	39.67 (34.45, 44.92)	38.06% (32.29%, 43.47%)	10.37% (6.30%, 15.55%)
Male	85,985 (69,594, 104,250)	11.74 (9.50, 14.24)	7.98 (6.54, 9.63)	34,936 (30,066, 40,863)	4.77 (4.11, 5.58)	3.42 (2.91, 4.03)	719,427 (621,521, 840,770)	98.24 (84.87, 114.81)	66.57 (57.39, 76.71)	46.60% (40.00%, 52.54%)	10.42% (6.36%, 15.74%)
Female	19,647 (14,824, 26,549)	2.81 (2.12, 3.80)	1.66 (1.26, 2.26)	9,793 (7,680, 13,341)	1.40 (1.10, 1.91)	0.81 (0.64, 1.11)	183,520 (147,188, 240,695)	26.28 (21.08, 34.47)	15.45 (12.39, 20.21)	7.62% (5.33%, 10.78%)	10.22% (6.13%, 15.25%)

All estimates are presented with 95% uncertainty intervals (UIs). ASDR, age-standardized DALY rate (per 100,000); ASIR, age-standardized incidence rate (per 100,000); ASMR, age-standardized mortality rate (per 100,000); CDR, crude DALY rate (per 100,000); CIR, crude incidence rate (per 100,000); CMR, crude mortality rate (per 100,000); DALY, disability-adjusted life year; FPG, fasting plasma glucose.

riod, with an AAPC of -0.32% (95% CI: -0.44% to -0.17% , $P < 0.001$). However, marked period-specific fluctuations were observed. The ASIR declined continuously from 1990 to 2014, with the steepest decrease during 2000–2003 (APC = -3.97% , 95% CI: -4.80% to -1.76% , $P = 0.03$). After 2014, the trend reversed and began to increase, with a particularly pronounced rise during 2020–2023 (APC = 5.05% , 95% CI: 3.41% to 8.27% , $P < 0.001$). Sex-specific analyses showed that the increase in crude incidence was more pronounced in males than in females, with AAPCs of 2.29% (95% CI: 2.13% to 2.47%) and 0.86% (95% CI: 0.77% to 0.95%), respectively. The overall decline in ASIR was more marked in females than in males, with AAPCs of -1.56% (95% CI: -1.65% to -1.47%) and -0.32% (95% CI: -0.49% to -0.14%), respectively.

For mortality, the crude mortality rate also showed a significant overall increase from 1990 to 2023, with an average annual increase of 1.52% (95% CI: 1.39% to 1.70% , $P < 0.001$). During the same period, the ASMR showed an overall decline, with an AAPC of -1.31% (95% CI: -1.44% to -1.15% , $P < 0.001$), although the decline was not monotonic. Specifically, the ASMR increased during 2014–2017 (APC = 3.46% , 95% CI: 1.81% to 4.47%), declined again during 2017–2020, and then increased during 2020–2023 (APC = 4.39% , 95% CI: 2.77% to 7.55%). In males and females, the AAPCs of the crude mortality rate were 0.50% and 1.76% , respectively, whereas the corresponding AAPCs of the ASMR were -1.09% and -2.31% , respectively (Fig. 1b, Supplementary Tables 1 and 2). Given the high recurrence rate of bladder cancer and its substantial effect on quality of life, temporal trends in DALYs were also analyzed. The crude DALY rate increased overall from 1990 to 2023 (AAPC = 0.79% , 95% CI: 0.67% to 0.96% , $P < 0.001$), whereas a decline was observed in females (AAPC = -0.35% , 95% CI: -0.43% to -0.27% , $P < 0.001$). Consistent with the incidence and mortality patterns, the ASDR declined overall from 1990 to 2023 (AAPC = -1.62% , 95% CI: -1.76% to -1.45% , $P < 0.001$), but rebounded in recent years, increasing during 2020–2023 (APC = 4.25% , 95% CI: 2.63% to 7.39% , $P < 0.001$) (Fig. 1c, Supplementary Tables 1 and 2).

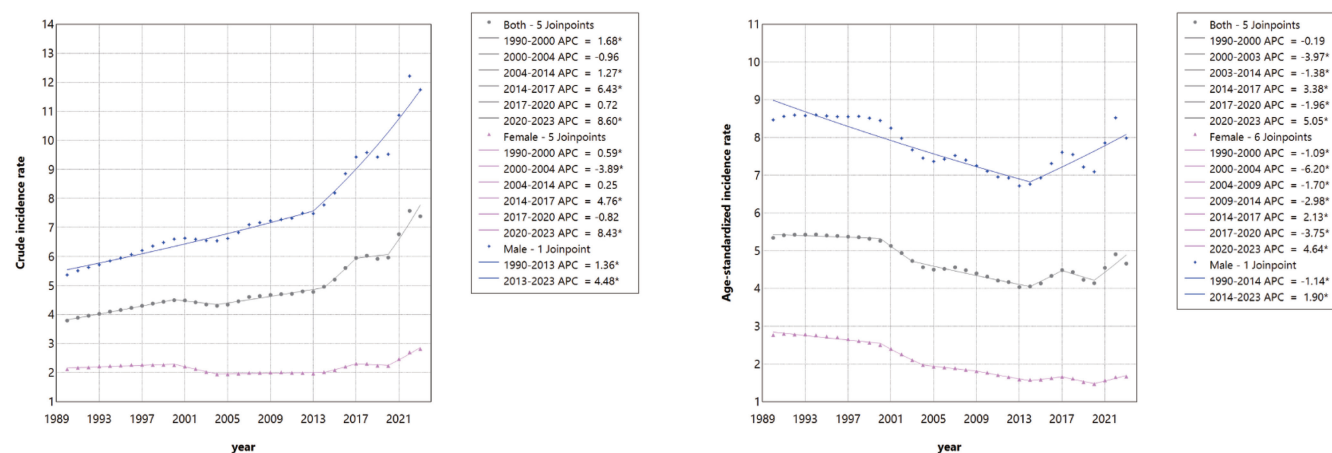
Trends in bladder cancer burden attributable to modifiable risk factors were also assessed. For bladder cancer deaths attributable to tobacco, the ASMR showed an overall decline (AAPC = -1.53% , 95% CI: -1.71% to -1.33%), although an upward, non-significant trend was observed during 2013–2023 (APC = 0.33% ,

$P = 0.33$). For bladder cancer deaths attributable to high FPG, the ASMR also declined overall (AAPC = -1.02% , 95% CI: -1.13% to -0.89%). A similar pattern of an initial decrease followed by a subsequent increase was observed (Supplementary Tables 1 and 2, Supplementary Fig. 1). Diagnostic statistics for the main Joinpoint models are presented in Supplementary Table 3. Across burden indicators and sex groups, Bayesian information criterion values ranged from -5.26 to -1.44 and root mean squared error values ranged from 0.05 to 0.38 . In sensitivity analyses varying the maximum number of joinpoints, the results were largely consistent with the main analysis. Reducing the maximum number from six to five did not change the selected joinpoints, AAPCs, recent trend segments, or corresponding APCs. When the maximum number was further reduced to four, fewer joinpoints were selected for some indicators, but the directions of the AAPCs and recent APCs generally remained unchanged; the exception was that the recent APC for female ASMR became statistically non-significant (Supplementary Table 4). In the sensitivity analysis excluding data from 2020 to 2023, AAPC estimates were lower across all indicators, while their directions remained largely unchanged, except for the crude mortality rate in females (Supplementary Table 5).

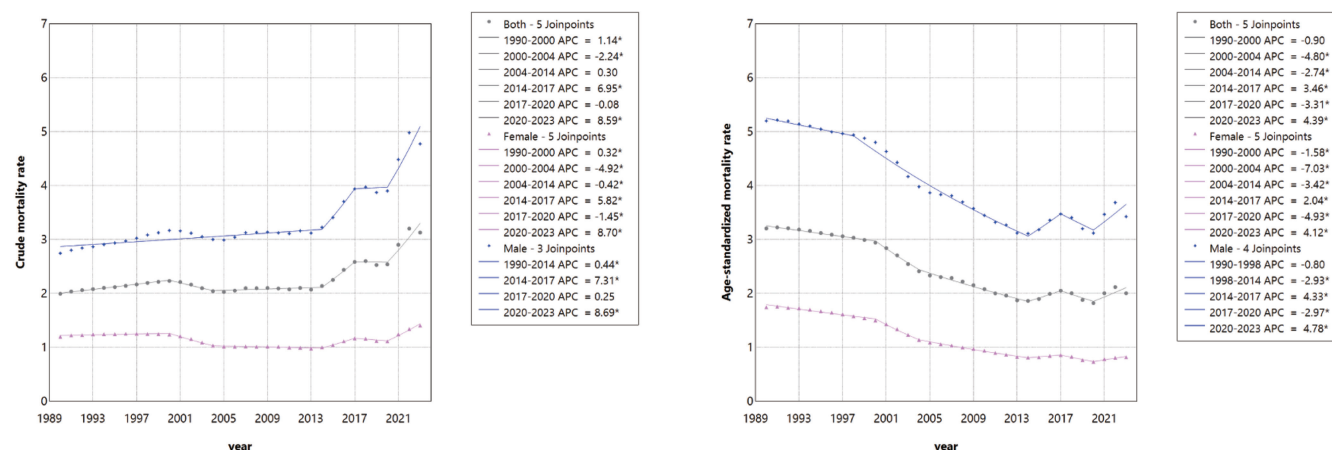
Age, period, and cohort effect analysis of BC burden in China, 1994 to 2023

In the age-period-cohort modelling, age and period were categorized into equal five-year intervals to ensure accurate derivation of birth cohorts, enhance model identifiability, and improve the stability and interpretability of age, period, and cohort effect estimates.²¹ Accordingly, the analysis used data from 1994 to 2023, allowing complete and comparable five-year period groupings across the study period. The age-specific temporal patterns of BC burden in China from 1994 to 2023 are shown in Figure 2 using local drifts and longitudinal age curves. For both incidence and mortality, local drift values were below zero in most age groups, indicating overall declines in age-specific rates over time. However, local drift increased progressively with age and approached or exceeded zero in the oldest age groups. For incidence, local drift values were 0.35% (95% CI: -0.07% , 0.78%) in the 85–89-year age group and 0.64% (95% CI: -0.31% , 1.61%) in the 90–94-year age group. For mortality, the corresponding values were -0.70% (95% CI: -0.97% , -0.43%) and -0.18% (95% CI: -0.72% , 0.36%), respectively, indicating stabi-

a Incidence



b Mortality



c DALY

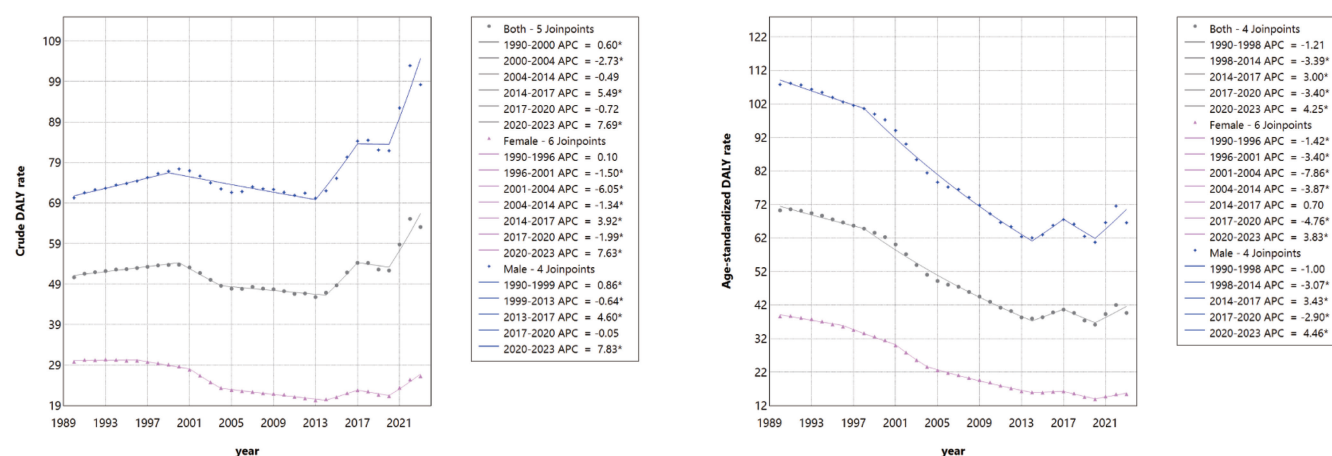


Fig. 1. Temporal trends in incidence (a), mortality (b), and DALYs (c) of bladder cancer in China, 1990–2023, based on Joinpoint regression analysis. In each panel, crude rates are shown on the left and age-standardized rates on the right. * $P < 0.05$. APC, annual percentage change; DALY, disability-adjusted life year.

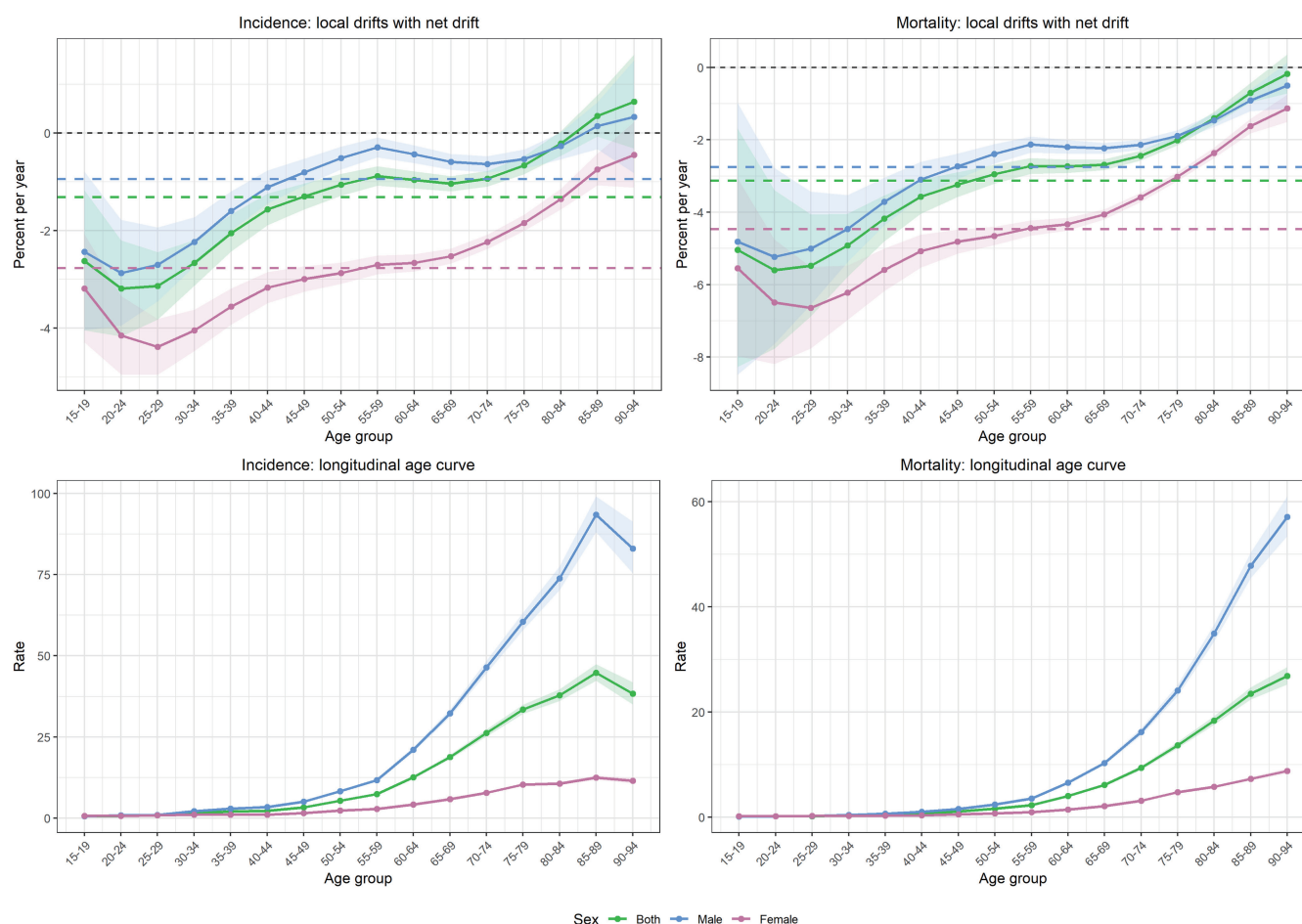


Fig. 2. Age-specific local drifts with net drift and longitudinal age curves for bladder cancer incidence and mortality in China, 1994–2023.

lization and possible reversal of age-specific trends in the oldest populations. Across most age groups, females had lower local drift values than males, indicating a greater decline over time. The longitudinal age curves showed marked age effects for both incidence and mortality. Age-specific incidence and mortality rates remained low at younger ages and increased substantially with advancing age, particularly after 60 years. Males consistently had higher rates than females across nearly all age groups.

Figure 3 presents the period and cohort RRs for bladder cancer incidence and mortality in China by sex. For both incidence and mortality, period RRs generally decreased over time, with earlier periods showing RRs above 1.0 and later periods showing RRs below 1.0 relative to the reference period (2004–2008). This decline was more pronounced in females. In males and in the overall population, however, incidence period effects rebounded from 2014–2018 onward, and the decline in mortality period effects became less pronounced over the same period. Cohort RRs for both incidence and mortality declined progressively across successive birth cohorts. For incidence, compared with the reference cohort (1951–1956), earlier birth cohorts had elevated risks, with RRs of 1.13 for both sexes, 1.09 for males, and 2.17 for females in the 1901–1906 cohort. Reduced risks were observed in later cohorts, with RRs decreasing to 0.37 for both sexes, 0.44 for males, and 0.21 for females in the 2001–2006 cohort. A similar pattern was observed for mortality. The downward cohort trend was particular-

ly pronounced among females, suggesting substantial generational improvements in bladder cancer risk. Model diagnostic statistics are presented in [Supplementary Table 6](#). No age-period cell had a dispersion-adjusted APC residual greater than 3, and the observed-versus-fitted rate mean absolute percentage error (MAPE) ranged from 2.97% to 3.47% across the six age-period-cohort models. In the sensitivity analysis using 10-year age groups and 10-year periods, the overall directions and patterns of age, period, and cohort effects were generally consistent with those in the main analysis ([Supplementary Figs. 2 and 3](#)).

Projections of BC burden in China, 2024 to 2030

Short-term projections of bladder cancer incidence and mortality in China from 2024 to 2030 were generated using BAPC models. The crude incidence rate was projected to increase steadily for both sexes combined, from 8.5 per 100,000 population in 2024 to 10.9 per 100,000 population in 2030 ([Fig. 4a](#)). Similar increases were projected by sex, from 12.6 to 16.1 per 100,000 population in males and from 3.0 to 4.4 per 100,000 population in females. The crude mortality rate was also projected to increase during the same period ([Fig. 4b](#)). For both sexes combined, the crude mortality rate was projected to rise from 3.3 per 100,000 population in 2024 to 4.0 per 100,000 population in 2030. Sex-specific projections showed similar upward trends, from 4.5 to 5.7 per 100,000 population in males and from 1.9 to 2.2 per 100,000 population

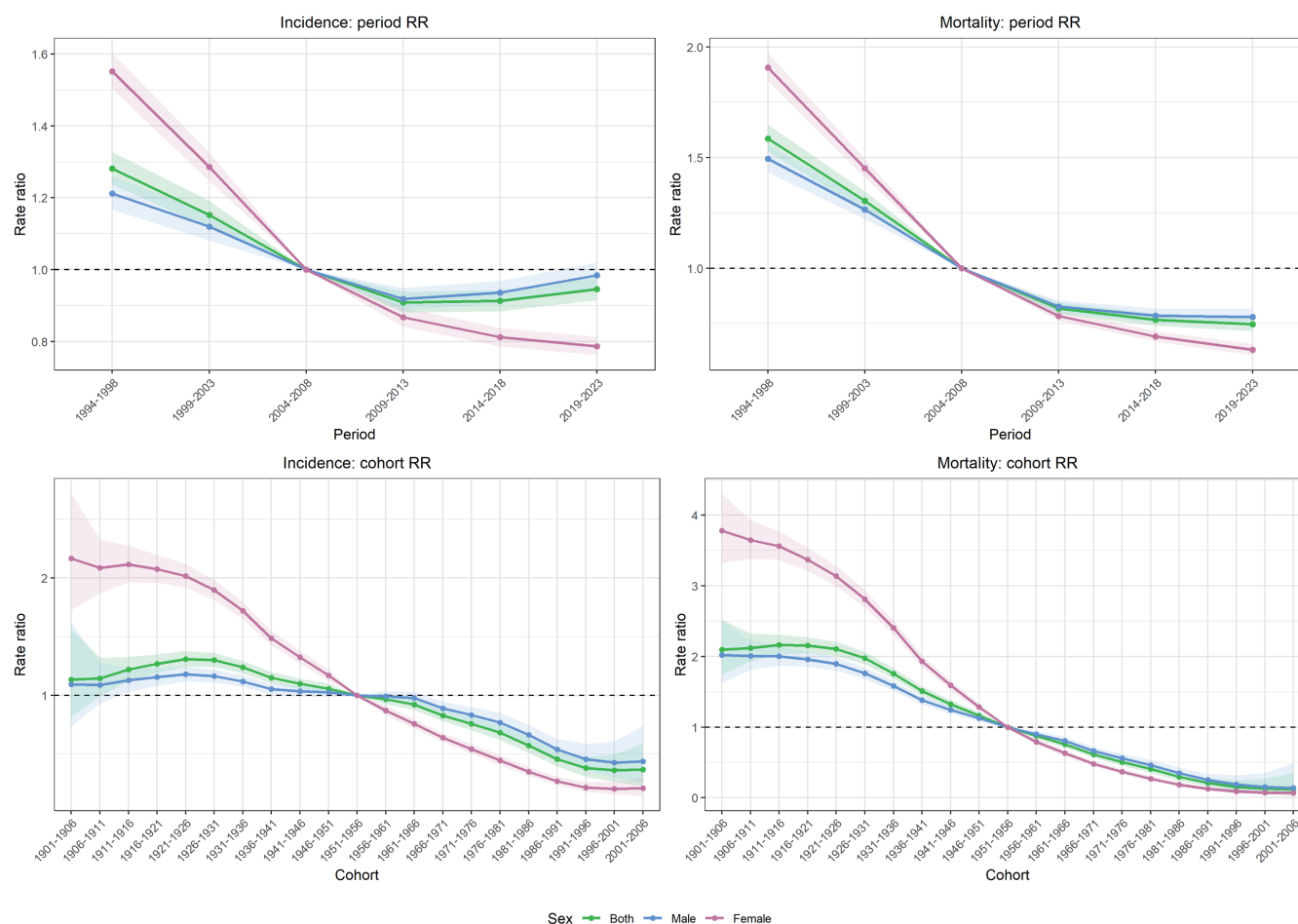


Fig. 3. Period and cohort effects on bladder cancer incidence and mortality in China, 1994–2023. Relative risks are set to 1 for the 2004–2008 period group and the 1951–1956 birth cohort. RR, relative risk.

in females. For ASIRs, a slight increase was projected from 2024 to 2030 (Fig. 4c). The ASIR for both sexes combined was projected to increase marginally from 5.1 to 5.2 per 100,000 population. In sex-specific analyses, the ASIR was projected to increase from 8.3 to 8.5 per 100,000 population in males and from 1.7 to 2.0 per 100,000 population in females. ASMRs showed divergent trends by sex (Fig. 4d). The ASMR for both sexes combined was projected to decline from 2.0 per 100,000 population in 2024 to 1.8 per 100,000 population in 2030. A similar decline was projected in males, from 3.4 to 2.9 per 100,000 population, whereas the ASMR in females was projected to increase slightly from 0.8 to 0.9 per 100,000 population. Model fit and residual diagnostics for the six BAPC models are presented in [Supplementary Table 7](#). Age-standardized rate MAPE values ranged from 0.13% to 2.76%, and the proportion of absolute Pearson residuals greater than 3 was 0% for five models and 2.35% for the incidence model in both sexes. In the sensitivity analysis using stronger smoothing priors, the projected trends were generally consistent with those from the main model ([Supplementary Figs. 4 and 5](#)).

Discussion

This study comprehensively profiled the burden of bladder cancer

in China using GBD 2023 data, integrating current burden estimates, long-term temporal trends, age-period-cohort patterns, and future projections, with incidence, mortality, and DALYs as the key outcome measures. The findings provide an updated overview of the epidemiology and evolving burden of bladder cancer in China and offer evidence to support priority setting, policy development, and strengthening of cancer control strategies.

The temporal trend analyses showed a divergence between crude and age-standardized trends. Age-standardized rates for incidence, mortality, and DALYs (AAPC = -0.32% , -1.31% , and -1.62% , respectively) declined overall, which may reflect population-level improvements in risk factor control and clinical management in recent decades. Smoking is one of the most established risk factors for bladder cancer; in China, 38.06% of bladder cancer deaths in 2023 were attributable to smoking, and current smokers have been reported to have an approximately threefold higher risk of bladder cancer than never-smokers.^{6,22} Previous studies have shown that smoking prevalence and smoking intensity among Chinese adults declined between 2010 and 2018, indicating progress in tobacco control.²³ This pattern is broadly consistent with our attributable-risk analysis, in which the ASMR attributable to tobacco declined overall, although this consistency should be interpreted as a population-level observation rather than direct evidence of causality. Long-term improvements in bladder cancer diagnosis

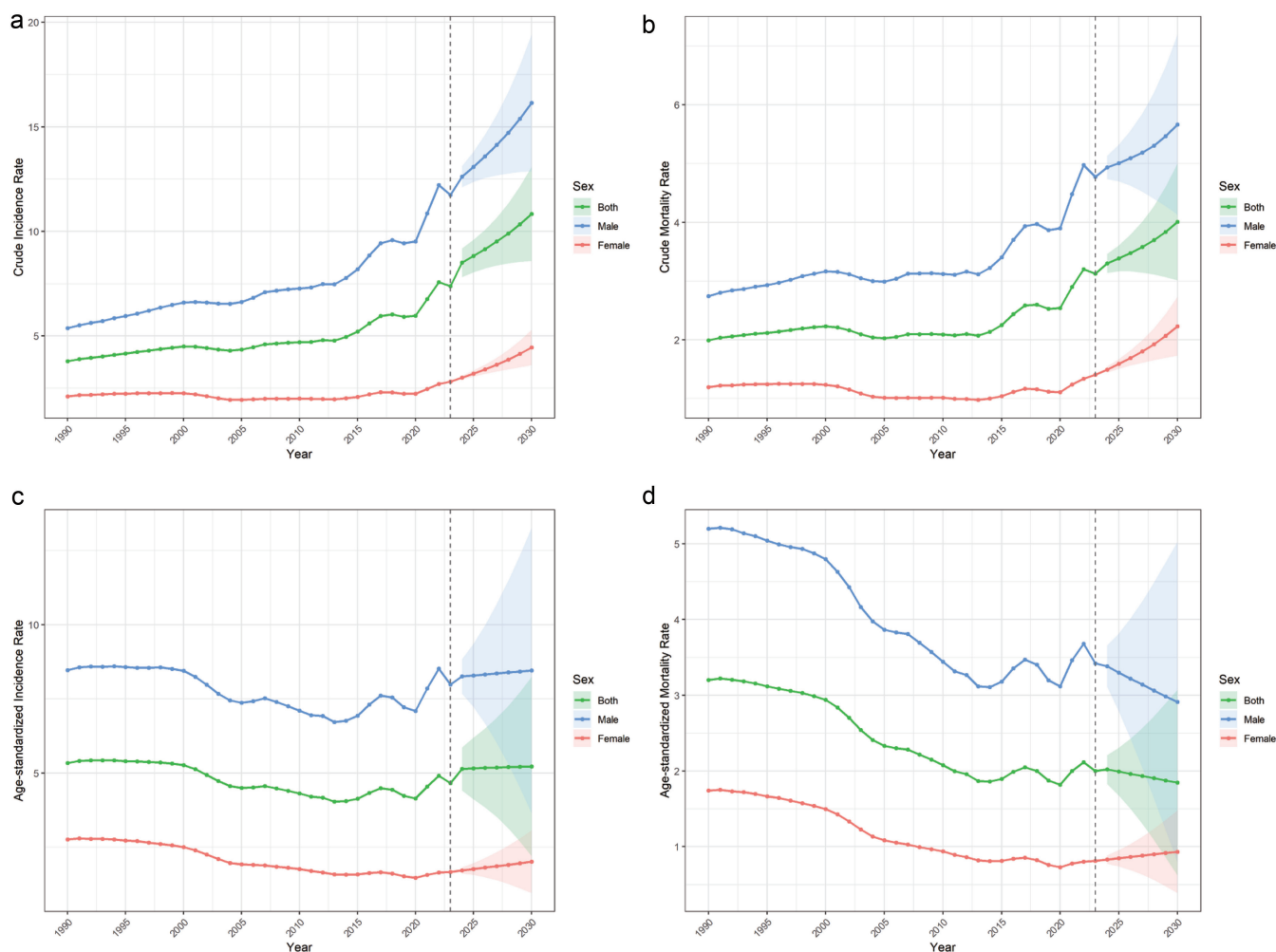


Fig. 4. Projected trends in crude incidence (a), crude mortality (b), age-standardized incidence (c), and age-standardized mortality (d) rates of bladder cancer in China by sex, 1990–2030.

and treatment may also have contributed to the declines in age-standardized mortality and DALY rates. Advances have included increasing standardization of transurethral resection, risk-adapted intravesical therapy, radical cystectomy, minimally invasive surgery, perioperative systemic treatment, and, more recently, immunotherapy and other novel systemic agents, all of which have expanded the treatment landscape for bladder cancer.^{24–26} However, crude incidence and mortality rates increased significantly (AAPC = 2.18% and 1.52%, respectively), suggesting that gains in risk control and clinical management may have been offset by population aging and expansion of high-risk age groups. Given the strongly age-related nature of bladder cancer, demographic aging has likely contributed substantially to the increasing absolute burden of the disease.^{22,27} These findings suggest that bladder cancer may continue to place increasing pressure on public health and health-care systems in China, underscoring the need for prevention and control strategies tailored to an aging population.

Although age-standardized incidence, mortality, and DALY rates generally declined from 1990 to 2023, these favorable trends reversed in recent years. Age-standardized incidence, mortality, and DALY rates began to rise after 2014, with more rapid increases during 2020–2023, as reflected by APCs of 5.05%, 4.39%, and

4.25%, respectively. The age-period-cohort analysis also supported this pattern: period and cohort RRs generally declined over time, suggesting long-term improvements in population-level conditions and risk profiles, but incidence period effects rebounded from 2014–2018 onward, and the decline in mortality period effects became less pronounced over the same period. These changes may be explained from several perspectives. First, improved case ascertainment and surveillance may have contributed to the observed increase. Over the past decade, China's cancer registration and surveillance systems have continued to expand and improve, which may have enabled more complete capture of incident cases and deaths.^{28,29} Second, wider availability of diagnostic procedures, increased health-care utilization, and improved access to urological services may have increased the likelihood of bladder cancer diagnosis, particularly among older adults and populations with previously limited access to specialized care.^{30,31} Third, changes in the spectrum of risk exposures during rapid modernization in China may also have contributed to the recent reversal in bladder cancer burden. Previous studies have reported substantial transitions in dietary and lifestyle patterns, including increased consumption of sugar-sweetened beverages and highly processed foods, more sedentary behavior, and a rising burden of metabolic

abnormalities such as obesity and diabetes.^{9,32–34} This interpretation is also consistent with our finding that the ASMR attributable to high FPG showed a recent upward trend. Finally, the increase in bladder cancer incidence and mortality during 2020–2023 should be interpreted cautiously. During the COVID-19 pandemic and immediate post-transition period, disruptions in health-care utilization, delayed diagnosis and treatment, catch-up of deferred care, and changes in reporting or registration may have affected burden estimates. The short-term fluctuation, characterized by increases from 2020 to 2022 followed by a decline in 2023, is consistent with special period effects during this interval. In line with this concern, the Joinpoint sensitivity analysis excluding data from 2020 to 2023 yielded lower AAPC estimates for incidence and mortality, indicating that trend estimates were influenced by this recent period. Continued monitoring of post-pandemic trends is therefore needed to distinguish transient period effects from sustained changes in bladder cancer burden.

The age-effect analysis showed that both incidence and mortality increased markedly with advancing age. Before 55 years of age, bladder cancer incidence and mortality remained relatively low and stable, possibly reflecting a shorter cumulative duration of carcinogenic exposure. After 55 years of age, both incidence and mortality increased substantially, reaching peaks at 85–89 years and 90–94 years, respectively. These findings further support bladder cancer as a strongly age-related malignancy, potentially associated with prolonged carcinogenic exposure, age-related immune decline, and reduced DNA damage repair capacity.^{35,36} Males consistently had higher incidence, mortality, and DALY rates than females. Several mechanisms may underlie this marked sex disparity. First, smoking, one of the most established risk factors for bladder cancer, is substantially more prevalent among men than among women in China.³⁷ Second, men are more likely to be employed in occupations involving exposure to chemical carcinogens, such as aromatic amines, which may further increase bladder cancer risk.³⁶ In addition, sex hormone signaling may contribute to the observed sex heterogeneity in bladder cancer risk. Previous studies suggest that androgen receptor signaling is more likely to promote bladder carcinogenesis and progression, whereas the role of estrogen receptor signaling appears to be subtype dependent, with estrogen receptor alpha showing more protective features and estrogen receptor beta more often associated with tumor-promoting effects.^{38,39}

The long-term declines in age-standardized incidence, mortality, and DALY rates suggest that substantial progress has been made in bladder cancer control in China. However, increasing crude rates driven by population aging, recent unfavorable shifts in age-standardized trends, and projections indicating stable incidence with only modest declines in mortality through 2030 collectively indicate that the burden of bladder cancer remains substantial. These findings emphasize the need for continued optimization of prevention and control strategies. The large attributable fractions for smoking and high FPG observed in this study indicate that primary prevention should remain a major focus of bladder cancer control. Smoking remained the leading modifiable contributor to bladder cancer mortality, accounting for 38.06% of deaths overall and 46.60% among men, while high FPG accounted for 10.37% of deaths. Early detection and timely treatment also warrant further strengthening. Prognosis varies markedly by stage at diagnosis: the five-year relative survival rate is approximately 73% for localized disease, but declines to 41% for regional disease and 9% for distant disease. Together with the recent upward shifts in ASMR, these findings indicate that early detection and timely management of

bladder cancer remain important areas for improvement. Cystoscopy, the diagnostic gold standard, is invasive and costly, which can reduce patient compliance and contribute to delayed evaluation. Although urine cytology is a common non-invasive adjunct in clinical practice, its utility is limited by suboptimal sensitivity, particularly for low-grade tumors.⁴⁰ U.S. Food and Drug Administration-approved urine biomarkers, such as bladder tumor antigen Stat and bladder tumor antigen TRAK, NMP22, and UroVysion fluorescence in situ hybridization (FISH), have shown higher sensitivity than cytology in selected settings; however, routine use is constrained by false-positive results, variable diagnostic performance, and cost considerations.³¹ These challenges highlight the need for effective, non-invasive, and clinically accessible tools for early detection of BC. Moreover, the marked age effect and persistent sex disparity observed in this study underscore the need for future research on risk-stratified early-detection strategies. Older adults, men, smokers, and individuals with metabolic risk factors may represent priority groups for bladder cancer risk assessment using non-invasive early-detection tools.

Several limitations should be acknowledged. First, although GBD estimates integrate multiple high-quality national data sources and apply standardized modelling frameworks to improve representativeness and comparability, potential bias related to data-source heterogeneity, data incompleteness, and uncertainty propagation from model-based estimates is inevitable. Second, methodological limitations of the statistical framework warrant caution. Because the age-period-cohort model used the estimable-function framework, the estimated period and cohort rate ratios should be interpreted as identifiable relative risk functions reflecting temporal variation rather than fully isolated independent effects. In addition, because of computational constraints associated with iteratively refitting non-linear models (Joinpoint, APC, and projection models) across posterior distributions and limitations in data availability, downstream trend analyses were conducted using point estimates. Therefore, although 95% uncertainty intervals were provided for descriptive burden estimates, incomplete propagation of input uncertainty into the forecasting and segmentation models may have underestimated the overall statistical variance. Third, although potential effects of diagnostic practices, expanding registry coverage, and improvements in health-care access on observed burden trends were discussed, quantitative adjustment for these historical shifts was not feasible because of data limitations; thus, trend inflections should be interpreted cautiously. Fourth, although GBD risk-outcome pairs were selected through a rigorous and standardized process, this study could not fully capture the complete etiologic spectrum of bladder cancer. Finally, the ecological design of this study limits causal inference. Future studies incorporating indicators of diagnostic practice, health-care access, and detailed exposure histories are needed to clarify the drivers of recent trend inflections and better support risk-stratified prevention and early-detection strategies.

Conclusions

In conclusion, although age-standardized rates of bladder cancer in China have declined over the past three decades, the overall disease burden remains substantial and continues to increase, largely because of population aging. The recent rebound in age-standardized incidence and mortality, together with the persistent impact of modifiable risk factors such as tobacco use and metabolic abnormalities, highlights the need for sustained and integrated control strategies. Future efforts should prioritize strengthening tobacco

control, improving metabolic risk management, and promoting early detection and timely intervention to curb the future burden of bladder cancer.

Supporting information

Supplementary material for this article is available at <https://doi.org/10.14218/CSP.2026.00038>.

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Conflict of interest

The authors have no conflicts of interest related to this publication.

Author contributions

Conceptualization and study design (XS, WC and CW); provision of study materials and tools (ZL, JX, XC and YQ); data collection and assembly (ZG, YW, FW and XD); data analysis (XS and WC); manuscript drafting (XS and CW); critical revision of the manuscript (WC and NL); supervision (NL). All authors had unrestricted access to the data and read and approved the final manuscript.

Ethical statement

Ethical approval and informed consent were not required for this study because all data used were publicly available and de-identified, and did not involve any direct human or animal experimentation. The study was conducted in accordance with the principles of the Declaration of Helsinki (as revised in 2024).

Data sharing statement

The data used in this study can be derived from the GBD 2023 (available at: <https://ghdx.healthdata.org/gbd-2023>).

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