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Original Research

Trends and age-period-cohort effect on incidence and mortality of prostate cancer from 1990 to 2017 in China

X. Liu, C. Yu, Y. Bi, Z.J. Zhang*

Department of Preventive Medicine, School of Health Sciences, Wuhan University, Wuhan 430071, China

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ABSTRACT

Objectives: The incidence and mortality trends of prostate cancer remain unknown in China. We examined secular trends in prostate cancer incidence and mortality rates and the net age, period, and cohort effects on them.

Study design: Trends were estimated using joinpoint regression, and the net age, period, and cohort effects were estimated by an age-period-cohort (APC) model with an intrinsic estimator (IE) algorithm.

Methods: Age-specific mortality rates of prostate cancer (1990–2017) were collected from the Global Burden of Disease (GBD) 2017 study, and the average annual percent change (AAPC) and relative risks (RRs) analyzed by joinpoint regression and APC model.

Results: Age-standardized rates significantly rose by 2.75% (95% confidence interval [CI]: 2.6, 2.9) for incidence but declined by 0.26% (95% CI: −0.4, −0.2) for mortality from 1990 to 2017. The joinpoint regression analysis showed that incidence rates significantly rose in all age groups, but mortality rates decreased in these age groups over the past three decades. In addition, compared to the younger age groups (15-19, 20-24, 25-29, 30-34, 35-39 and 40-44 age group), the older age groups (50-54, 55-59, 60-64 and 75-79 age group) showed more substantial increases in incidence and slighter declines in mortality. The age effect on incidence and mortality showed sharp increasing trends from 40 to 79 years, and period effect showed both of them continuously increased with advancing period, but cohort effect showed substantial decreasing trends from 1917–1921 to 2002–2006 birth cohort.

Conclusions: Age effect on incidence and mortality presented an increasing trend in older people, and period effect showed increasing trends. The incidence rate of prostate cancer is increasing at an alarming rate in all age groups, which may adversely impact the mortality rates. Mortality began to increase since 2005; thus, timely intervention should be conducted, especially for earlier birth cohorts at high risk.

* *Corresponding author*. Department of Preventive Medicine School of Health Sciences Wuhan University, No. 185 Donghu Road, Wuhan, 430071, China. Tel./fax: +86 27 6875-8648.

E-mail address: zhang22968@163.com (Zhi-Jiang Zhang).

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Introduction

Prostate cancer is the second most frequently diagnosed cancer in men worldwide and the fifth leading cause of cancer death in men.[1] Its incidence is increasing in many countries,[2,3] while the mortality is decreasing in developed countries and rising in developing countries.[1] In China alone, according to the 2015 National Central Cancer Registry (NCCR) of China, the incidence of prostate cancer ranked seventh in male cancers.[4] According to the Global Burden of Disease (GBD) 2017, 144,887 cases and 51,718 deaths of prostate cancer occurred in China. It is of public health significance to control the burden of prostate cancer.

There has also been significant improvement in screening, treatment (personalized therapy based on genetic factors, nanomedicine and traditional Chinese medicine, radical prostatectomy, or radical radiotherapy) and early detection of prostate cancer.[3–7] However, China has undergone a rapid aging transmission and lifestyle change; all these changes may impact the incidence and mortality rates differently for various age groups.[8–11] Trends in prostate cancer incidence and mortality in China remain unclear. Hence, it is crucial to examine time trends and age-period-cohort (APC) effect on prostate cancer incidence and mortality in China from 1990 to 2017.

Methods

Data source

The incidence and mortality rate of prostate cancer were obtained from the GBD 2017, which provided a comprehensive estimation of 315 incidence and death causes for 195 countries from 1990 to 2017, and incidence or mortality of prostate cancer (International Classification of Diseases [ICD]-10 code] for all ages in different provinces was age standardized by the GBD 2017 global age-standardized population.[12] The original data estimated by the GBD for incidence and mortality of prostate cancer in China were mainly from the Cause of Death Reporting System of the Chinese Centers for Disease Control and Prevention (CDC), Disease Surveillance Points (DSPs), and the Maternal and Child Surveillance System, which are considered to be nationally representative because they are based on a national scale.

Joinpoint Poisson regression

The identification of changes in the time trend is an important issue in the analysis of cancer mortality and incidence data, and such continuous changes were described by a joinpoint regression model. In the model, logarithmic transformation of the rates was carried out and the standard errors were calculated based on binomial approximation.[14] To determine the magnitude of the time trends for incidence and mortality rates, the average annual percent changes (AAPCs) and the corresponding 95% CIs were evaluated by joinpoint regression analysis.[15] Each P-value is found using Monte Carlo methods, and the overall asymptotic significance level is maintained through a Bonferroni correction. The AAPC was calculated as a geometrically weighted average of various annual percent change values from the regression analysis.[16] This analysis was performed using 'Joinpoint' software from the Surveillance Research Program of the US National Cancer Institute.

APC analysis

The APC model has been widely used in the fields of sociology and epidemiology over the past 80 years. The APC model is based on the Poisson distribution and can reflect temporal trends in cancer by age, period, and cohort and after adjustment for age, period, and cohort.[17,18] However, a non-identification problem may still exist because there is a linear relationship between the age, period, and cohort, which makes it difficult to estimate the unique set for every age, period, and cohort effect. To solve this problem, the intrinsic estimator (IE) method associated with the APC model was proposed by Yang et al.[19] and Fu[20] to decompose three temporal trends and provide unbiased and relatively efficient estimation results. In this study, we fitted two-factor models and three-factor models and chose the best-fitting models to conduct the APC analysis. The two-factor models were age-period (AP), age-cohort (AC), and period-cohort (PC), which were fitted with Poisson log-linear model. The three-factor models were APC models solved with a conventional constrained Poisson log-linear model estimator (APC-C) and the intrinsic estimator (APC with IE method). Smaller values for Akaike's information criterion (AIC) and Bayesian information criterion (BIC) with parameter penalty terms denote a better fit. We selected APC (IE) models for analyzing prostate cancer data because the results indicated IE method provided a best fit compared with the other models (Supplementary Table A).

In the APC model with IE method, the age-specific rates were appropriately recoded into successive 5-year age groups (15–19, 20–24, ..., 75–79 years), consecutive 5-year periods from 1990 to 2017, and correspondingly consecutive 5-year birth cohorts (1917–1921, 1922–1926, ..., 1997–2001, 2002–2006) to estimate net age, period, and cohort effects of prostate cancer incidence and mortality. In this model, the groups younger than 15 years and groups older than 80 years were excluded. The APC model could be expressed as follows:

$$Y_j = \mu + \alpha\ age_j + \beta\ period_j + \gamma\ cohort_j + \varepsilon_i$$

where Y_j denoted the response variable—the net effect on prostate cancer incidence or mortality for group j, α, β, and γ denoted the coefficient of age, period, and cohort of APC model, and μ denoted the intercept of the model. ε_i denoted the residual of the APC model.

The APC-IE method present estimated coefficients for the age, period, and cohort effects (Supplementary Table B), and then these coefficients were calculated to the exponential value ($\exp(coef.) = e^{coef.}$) which denotes the incidence and mortality relative risk (RR) of a particular age, period, or birth cohort relative to each average level[21] (Table 2). Fig. 5 was also plotted to reflect the age, period, and cohort effect trends based on the exponential value. The APC model was

Table 1 – The average annual percent changes (AAPC) in prostate cancer incidence and mortality, 1990–2017.

Age group (year)	Incidence		Mortality	
	AAPC	95% CI	AAPC	95% CI
ASR	1990–2017: 2.75	(2.6, 2.9)	1990–2017: −0.26	(-0.4, −0.2)
	1990–2004: 1.84	(1.6, 2.1)	1990–2004: −0.47	(−0.5, −0.4)
	2005–2017: 3.60	(3.5, 3.7)	2005–2017: 0.38	(0.3, 0.5)
15–19	1.79*	(1.5, 2.1)	−3.28*	(−3.7, −2.9)
20–24	2.00*	(1.8, 2.3)	−3.21*	(−3.6, −2.8)
25–29	2.57*	(2.1, 3.0)	−2.82*	(−3.3, −2.3)
30–34	3.03*	(2.5, 3.5)	−2.39*	(−2.8, −1.9)
35–39	3.26*	(2.9, 3.6)	−1.97*	(−2.2, −1.7)
40–44	2.68*	(2.4, 2.9)	−2.47*	(−2.7, −2.2)
45–49	3.71*	(3.4, 4.0)	−1.65*	(−1.9, −1.4)
50–54	4.06*	(3.8, 4.3)	−1.34*	(−1.5, −1.2)
55–59	4.03*	(3.7, 4.3)	−1.03*	(−1.2, −0.9)
60–64	3.99*	(3.7, 4.3)	−0.82*	(−1.0, −0.7)
65–69	3.82*	(3.5, 4.1)	−0.65*	(−0.8, −0.5)
70–74	3.06*	(2.9, 3.3)	−0.73*	(−0.8, −0.6)
75–79	2.35*	(2.2, 2.5)	−0.57*	(−0.7, −0.5)

ASR, age-standardized rate; CI, confidence interval. Incidence and mortality for prostate cancer were age standardized by the GBD 2017 global age standard population.
*Significantly different from 0 at alpha = 0.05 ($P < 0.05$).

performed using the Stata 12.0 software (StataCorp, College Station, TX, USA).

Results

Descriptive analysis of incidence and mortality rates

Trends in the crude incidence rate (CIR), age-standardized incidence rate (ASIR), crude mortality rate (CMR), and age-standardized mortality rate (ASMR) at all a@ges for prostate cancer from 1990 to 2017 are shown in Fig. 1. Generally, for incidence of prostate cancer, CIR and ASIR significantly increased from 1990 to 2017. ASMR experienced a slight decrease during 1990–2005, and then it slightly increased from 2005 to 2017. CMR for prostate cancer showed an obvious upward trend since 1990.

Trends in age-specific incidence and mortality rates using joinpoint regression analysis

Table 1 shows the AAPCs of prostate cancer incidence and mortality rates in China from 1990 to 2017. Age-standardized rates significantly rose by 2.75% (95% CI: 2.6, 2.9) for incidence but declined by 0.26% (95% CI: −0.4, −0.2) for mortality over the last few decades. Moreover, from 1990 to 2004, ASIR significantly rose by 1.84% (95% CI: 1.6, 2.1), but ASMR declined by 0.47% (95% CI: −0.5, −0.4); from 2005 to 2017, ASIR still significantly rose (AAPC: 3.60%; 95% CI: 3.5, 3.7) while ASMR began to rise (0.38%: 0.3, 0.5). For age-specific incidence rates, significant increases were observed in all age groups (15–19, 20–24 … and 75–79 years), but mortality rates declined in all age groups. In addition, compared with the older age groups, the younger age groups showed more substantial increases in incidence and slighter declines in mortality. Overall, the incidence of prostate cancer has increased, while its mortality has decreased among all age groups over the past three decades.

The variation of age, period, and cohort on incidence and mortality rates

Fig. 2 presents trends of the age-specific incidence and mortality in 1992, 1997, 2002, 2007, 2012, and 2017. Incidence and mortality rates showed no changes from 15–19 to 35–39 years, while the rates almost exponentially increased with advancing age from 40–44 to 75–79 years. Both incidence and mortality rates in older population were higher than those in younger people.

Fig. 3 shows the variation trends of prostate cancer incidence and mortality of different age groups from 1992 to 2017. Incidence rates almost increased with advancing time among all age groups, while mortality rates showed a slight downward trend from 1992 to 2017. The incidence and mortality rates of older groups in Fig. 3b were much higher than those of younger groups in Fig. 3a.

Fig. 4 shows the cohort-based variation of age-specific incidence and mortality. Incidence rates of prostate cancer increased continuously with advancing year of birth, except for the younger age groups (15–19, 20–24, 25–29, 30–34, 35–39 and 40–44 years) which showed no material changes. However, the mortality rates decreased continuously for the older age groups (50–54, 55–59, 60–64 and 75–79 years), while similarly no decreases were observed in the younger age groups (15–19, 20–24, 25–29, 30–34, 35–39, 40–44 and 45–49 years); note that the age group 65–69 and 70–74 years showed a decrease in the earlier birth cohort and subsequently an increase in the later birth cohort. Incidence and mortality in younger people were lower than those in the older people. The cohort effects span 89 years. Because age and period effects on the incidence and mortality were confounded, the independent cohort effects were not found.

Table 2 – Prostate cancer incidence and mortality relative risks due to age, period, and cohort effects.

Factor	Incidence			Mortality		
	RR	95% CI	P-value	RR	95% CI	P-value
Age (years)						
15–19	0.09	0.01–1.07	0.056	0.10	0.00–13.74	0.364
20–24	0.14	0.03–0.77	0.024	0.13	0.00–5.77	0.289
25–29	0.20	0.05–0.79	0.022	0.14	0.00–4.10	0.256
30–34	0.21	0.06–0.74	0.015	0.15	0.01–3.10	0.220
35–39	0.20	0.06–0.67	0.009	0.15	0.01–2.40	0.182
40–44	0.26	0.09–0.72	0.010	0.22	0.02–1.96	0.175
45–49	0.60	0.29–1.25	0.173	0.49	0.11–2.30	0.368
50–54	1.37	0.80–2.36	0.255	1.12	0.37–3.40	0.845
55–59	2.99	2.00–4.49	0.000	2.78	1.22–6.33	0.015
60–64	6.05	4.44–8.26	0.000	6.45	3.21–12.96	0.000
65–69	9.84	7.39–13.09	0.000	12.44	5.82–26.57	0.000
70–74	14.31	10.26–19.94	0.000	22.49	8.70–58.09	0.000
75–79	16.77	10.95–25.68	0.000	38.07	11.39–127.18	0.000
Period						
1992	0.45	0.31–0.66	0.000	0.80	0.34–1.86	0.597
1997	0.61	0.47–0.77	0.000	0.85	0.50–1.43	0.543
2002	0.83	0.73–0.95	0.007	0.92	0.73–1.17	0.502
2007	1.17	1.03–1.34	0.019	1.01	0.79–1.28	0.932
2012	1.66	1.31–2.10	0.000	1.16	0.68–1.96	0.585
2017	2.27	1.58–3.25	0.000	1.37	0.59–3.18	0.463
Cohort						
1917–1921	4.48	2.20–9.12	0.000	3.91	0.77–19.85	0.100
1922–1926	3.49	1.97–6.18	0.000	3.48	0.91–13.32	0.068
1927–1931	2.80	1.77–4.41	0.000	3.08	1.03–9.24	0.045
1932–1936	2.26	1.57–3.26	0.000	2.68	1.07–6.74	0.035
1937–1941	1.87	1.36–2.57	0.000	2.35	1.01–5.44	0.046
1942–1946	1.58	1.14–2.18	0.005	2.02	0.84–4.87	0.117
1947–1951	1.42	0.95–2.11	0.085	1.75	0.61–4.99	0.296
1952–1956	1.31	0.79–2.17	0.290	1.56	0.43–5.67	0.501
1957–1961	1.13	0.60–2.14	0.702	1.29	0.26–6.34	0.754
1962–1966	0.98	0.45–2.15	0.962	1.05	0.15–7.46	0.958
1967–1971	0.87	0.34–2.26	0.776	0.90	0.08–9.76	0.928
1972–1976	0.73	0.23–2.30	0.586	0.71	0.04–12.93	0.820
1977–1981	0.58	0.15–2.33	0.444	0.56	0.02–17.33	0.738
1982–1986	0.51	0.11–2.37	0.388	0.45	0.01–26.98	0.704
1987–1991	0.43	0.08–2.37	0.332	0.36	0.00–45.83	0.677
1992–1996	0.35	0.05–2.68	0.311	0.27	0.00–119.89	0.674
1997–2001	0.27	0.02–4.66	0.367	0.20	0.00–784.84	0.704
2002–2006	0.22	0.00–47.37	0.581	0.16	0.00–471644.12	0.810

RR: relative risk [RR = exp(coefficient)]; CI: confidence interval.

The age, period, and cohort effects on incidence and mortality using APC (IE) analysis

Age effect

After controlling for period and cohort effects, the age effect on prostate cancer showed that both incidence and mortality risk continuously increased with advancing age from 40 to 79 years (Fig. 5a, Table 2). This finding indicated that prostate cancer incidence and mortality significantly increased with advancing age, mainly in the older people. From the age groups 15–19 to 75–79 years, the incidence risk increased by 178.10 times and mortality risk increased by 365.52 times. These two values were computed by the coefficients.

Period effect

The period effect on incidence and mortality presented remarkable increasing and slight increasing trends from 1992 to 2017, respectively (Fig. 5b, Table 2). During the period, the risks of prostate cancer incidence and mortality increased by 5.04 and 1.72 times, respectively. Seemingly, mortality risks substantially increased from 2007 (RR = 1.01; 95% CI 0.79, 1.28) to 2017 (RR = 1.37; 95% CI 0.59, 3.18). However, the period effect on mortality in Fig. 5b differs from that in Fig. 3b that showed mortality rates have slightly decreased from 1992 to 2017, which are assumed to be caused by the confounding of one or both of the age and cohort effects.

Cohort effect

The cohort effect presented the incidence risk continuously decreased from the earlier birth cohort to the later birth cohort, as well as the mortality (Fig. 5c, Table 2). From 1917–1921 to 2002–2006 birth cohort, the risk of prostate cancer incidence and mortality significantly decreased by 95.08% and 74.43%, respectively. However, the decreasing cohort effects in Fig. 5c differ from those in Fig. 4 that showed increasing trend in incidence rates and decreasing trends in

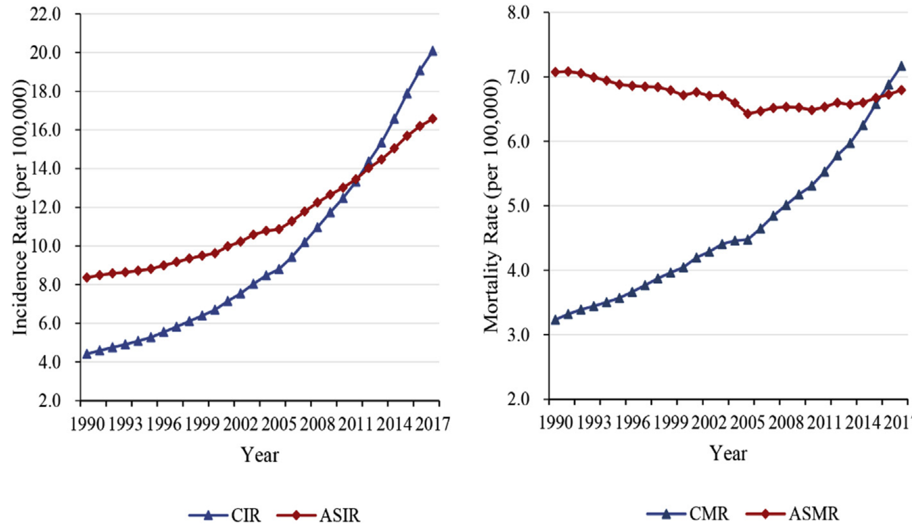

Fig. 1 – Trends of the crude rates and age-standardized rates for prostate cancer from 1990 to 2017, at all ages. CIR, crude incidence rate; ASIR, age-standardized incidence rate; CMR, crude mortality rate; ASMR, age-standardized mortality rate.

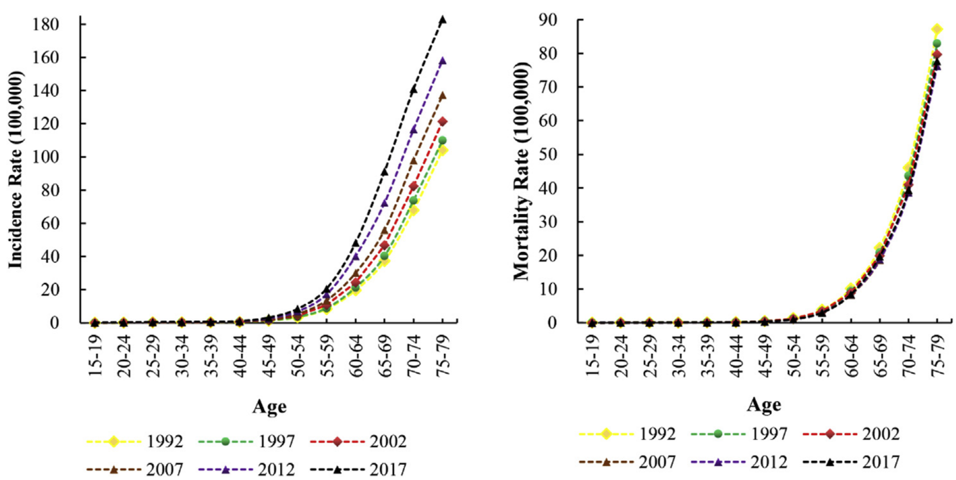

Fig. 2 – Age-specific incidence and mortality of prostate cancer in China from 1990 to 2017.

mortality rates almost among older people, which are assumed to be caused by the confounding of one or both of the age and period effects.

Discussion

This study presented the secular trends in incidence and mortality from prostate cancer in China. Joinpoint regression analysis showed incidence rates increased while mortality rates decreased among all age groups. The overall ASIR of prostate cancer significantly increased from 1990 through 2017, which was consistent with a previous study about burden of prostate cancer in China,[22] while our findings about the ASMR of prostate cancer is not consistent with that of this study which showed the ASMR increased from 1990 to 2013.[22] The mortality experienced a slight decrease during the period 1990–2005; however, this trend reversed beginning in the year 2005, which may have been driven by urbanization, reform, and rapid economic transitions. As reported, the urbanization process has progressed faster than the economic growth since 2004 in China,[23] and in March 2014, China unveiled the New-style Urbanization Plan (2014–2020).[24] This situation urgently requires the implementation of effective measures to reduce increasing mortality rate of prostate cancer in China. In general, we conducted this study focused on the incidence and mortality trends of prostate cancer using APC analysis with IE method to explore the cause of prostate cancer trends and assess the effect of public health control policies. Therefore, the three effects on incidence and mortality of prostate cancer were discussed preliminarily in the following section.

Age effect on prostate cancer explained incidence and mortality remarkably increased with advancing age mainly in older people, which might be mainly related to China's aging transition.[25] Previous studies have demonstrated that older

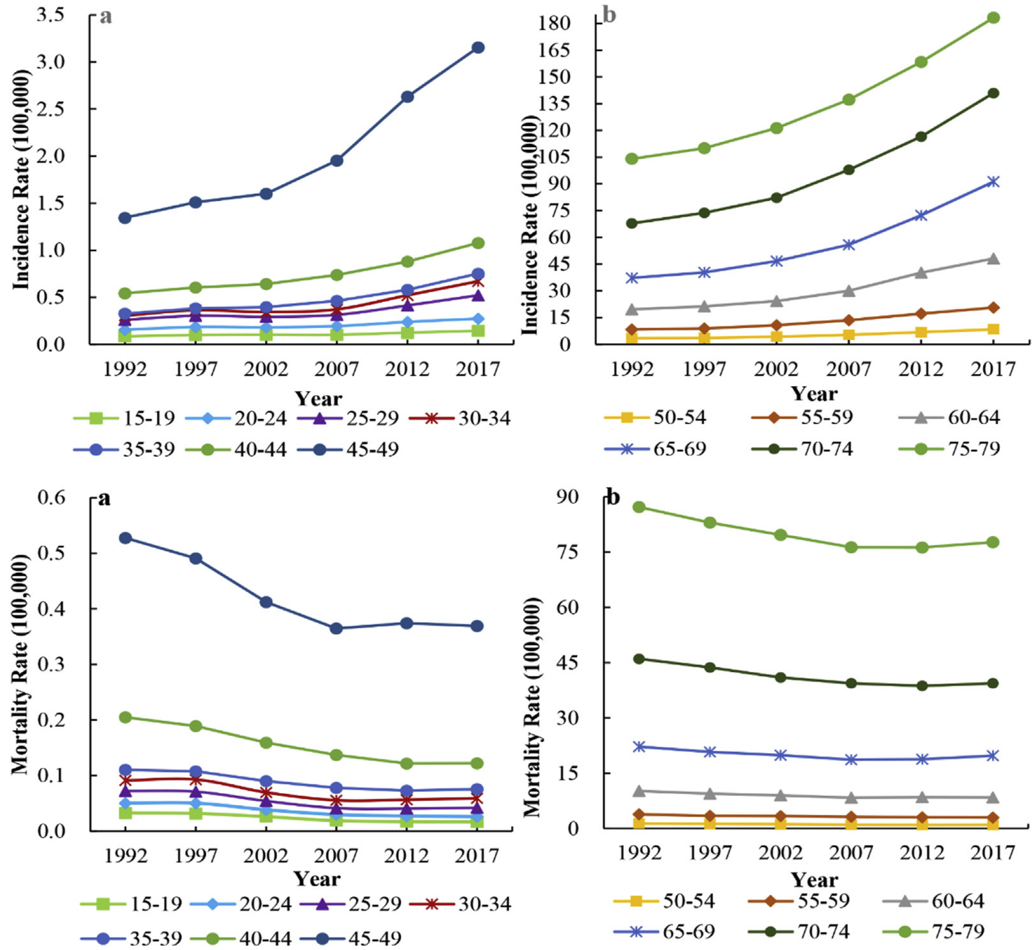

Fig. 3 – Incidence and mortality for prostate cancer among different age groups from 1990 to 2017. (a) 15–49 years old; (b) 50–79 years old.

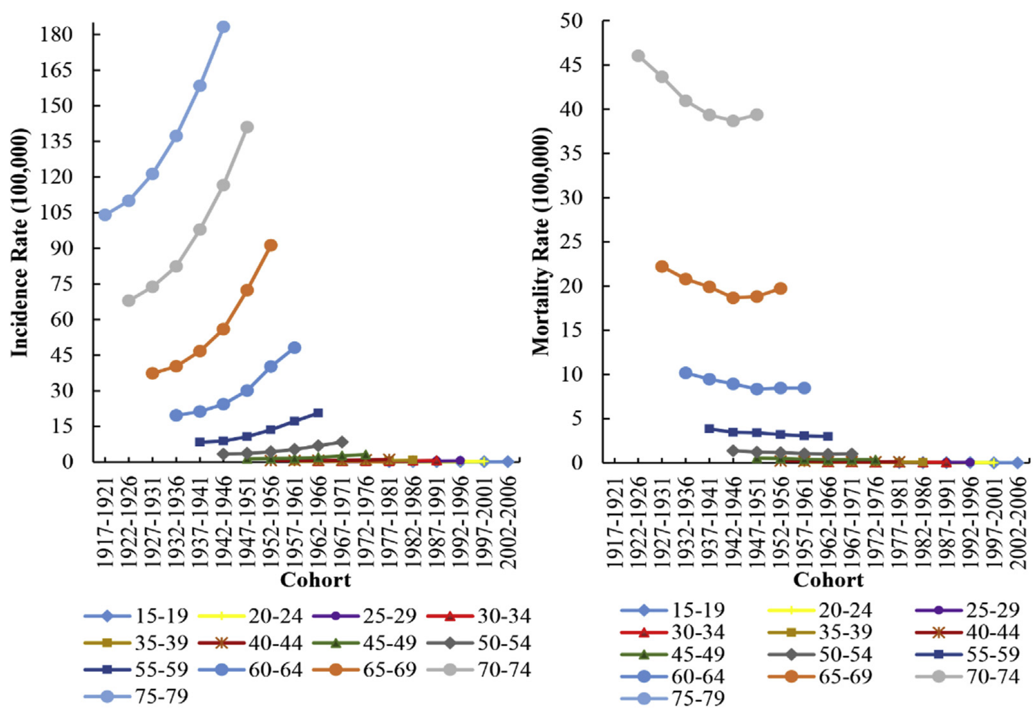

Fig. 4 – Cohort-based variation of age-specific incidence and mortality for prostate cancer.

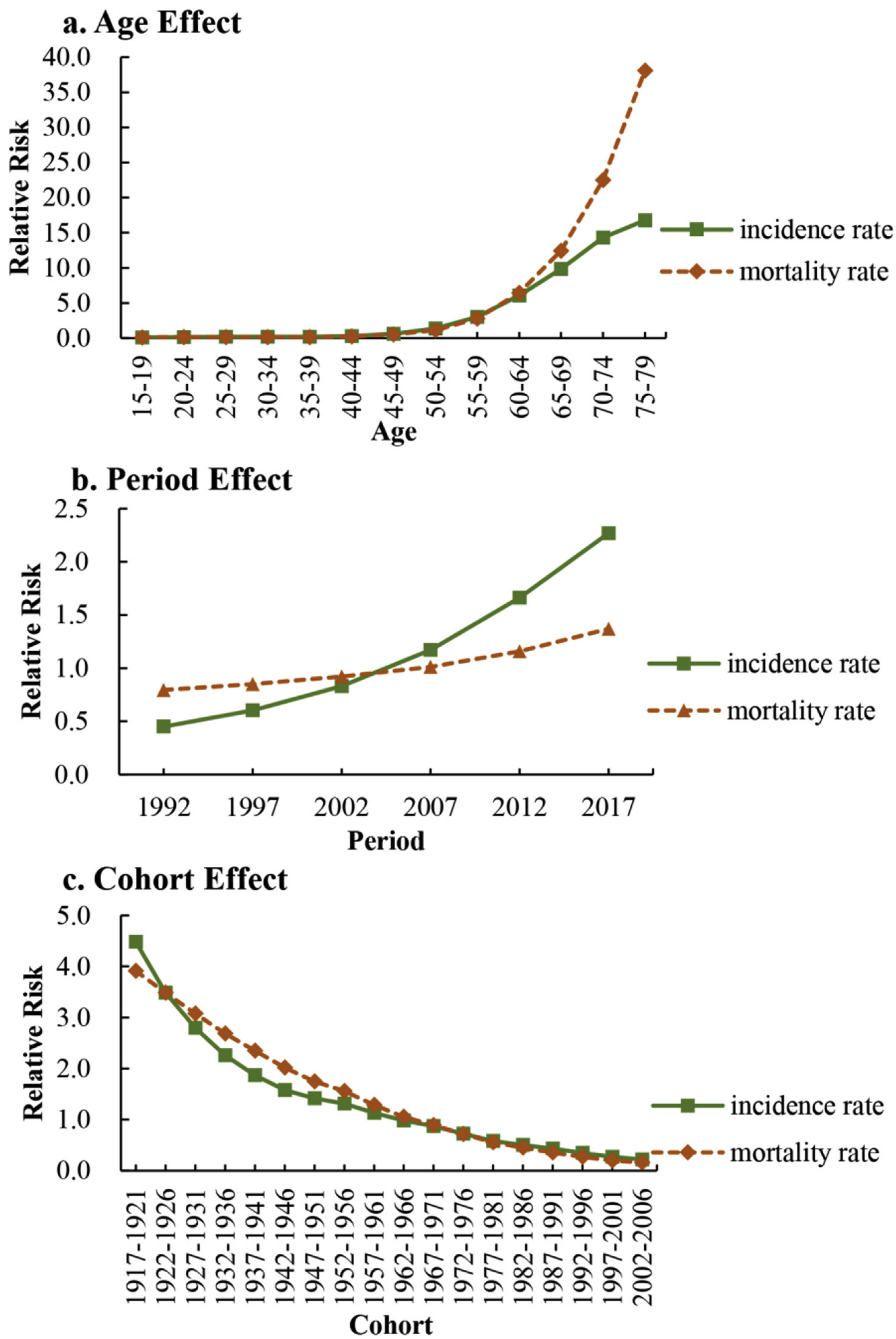

Fig. 5 – Prostate cancer incidence and mortality relative risks due to (a) age; (b) period; and (c) cohort effects.

men with high-risk prostate cancer tend to be older at diagnosis and is often undertreated with androgen deprivation alone,[26,27] and rapid aging is observed from 1980 to 2010 in China.[28] In addition, prostate cancer detected in older patients usually experience worse prognosis and failure rate which is significantly higher in them than in matched younger patients.[29] In our study, age effect showed that the increasing trends, which is consistent with the study by Ko et al.[29] Prostate cancer is considered a disease of older men (aged >65 years), but this study showed the incidence and mortality significantly increased in young men aged <40 years. It is worthwhile to note that these early-onset prostate cancer may be different from those diagnosed at an older age in terms of etiology and prognosis.[30] All these factors may cause the increasing age effect on prostate cancer incidence and mortality in older people in China.

Period effect is usually influenced by a complex set of historical events and environmental factors, such as wars, economic crises, epidemics of infectious diseases, public health interventions, and socio-economic development. The prevalence of tobacco smoking, one of the major risk factors, was closely associated with risk of prostate cancer,[31] and in Chinese men, current smoking was associated with high prostate cancer incidence.[32] A recent systematic meta-analysis showed that smoking appears to be a modifiable risk factor for prostate cancer mortality.[33] In China, there are four national tobacco surveys among people aged 15 years and older during 1984–2010,[18] which showed tobacco smoking rates gradually decreased in both males and females over the last two decades; thus, the improvement of smoking prevalence was not possibly the reason for these increasing period trends. However, the association between smoking and incidence of prostate cancer is still controversial, and an inverse relationship was reported (risk ratio: 0.90; 95% CI 0.85, 0.96),[33] which need to be further studied. Treatments for prostate cancer have been improved over the past decades, including personalized therapy based on genetic factors, nanomedicine and traditional Chinese medicine, radical prostatectomy, or radical radiotherapy,[6,7] while improvements in survival of those patients seemingly did not impact the increasing period effect on its mortality in the present study.

Prostate-specific antigen (PSA) screening is possibly the reason of continuously increasing period trend from 1992 to 2017. PSA screening has been the technology used worldwide for prostate cancer at an early and curable stage; however, PSA screening may have led to overdiagnosis and overtreatment of clinically insignificant cancers.[34,35] Recent studies are ongoing to confirm the role of PSA testing on prostate cancer[11,36] because the PSA screening is very controversial. In the early 1990s, PSA testing was introduced in the world for over 20 years,[3,37] and increasing PSA screening might have impacted the prostate cancer incidence or mortality in many developed countries,[38,39] such as leading to a decrease in mortality in the United States.[34] However, in recent years, routine PSA screening is no longer recommended for males because studies in America showed it potentially had serious side-effects related with prostate cancer treatment from 1985 to 2000 and frequent overdiagnosis were concerned, and some studies are ongoing to evaluate new tests for prostate cancer.[36,40] In Germany, the PROBASE is a current study researching a recommendation for PSA screening.[37] Furthermore, a recent study reported that continuing PSA screening for men aged <70 years could prevent greater than 50% of avoidable deaths of prostate cancer,[41] although PSA screening remains popular in some developing countries such as China and Japan[42,43] and developed countries such as the US, as well as some European countries.[34,35] PSA screening levels in Asian men are almost identical, and the variation of PSA testing and clinical treatment might be the major contributing factor for increasing incidence and mortality in Asia.[44] In China, studies reported a high positive detection rate of prostate cancer in different PSA levels since 2000 to 2005.[45] Although the value of serum PSA screening remains controversial, PSA screening is recommended to facilitate the early diagnosis of prostate cancer in high-risk groups in China.[7] PSA screening improves the detection rate of localized prostate cancer in China,[2] and previous study proposed PSA testing should be offered earlier in men with life expectancy over 10 years and men at high risk of prostate cancer in China.[46] But the coverage of PSA screening in China remains unknown, and there is still a need for new complementary diagnostic methods.[2] Currently, there are different treatment strategies for prostate cancer in China, mainly including radical treatment (surgery, radiotherapy) and local treatment (particle implantation, ablation) for localized prostate cancer and endocrine therapy, chemotherapy, targeted therapy, and immunotherapy for advanced prostate cancer.[2] However, the period effect did not show any declines over the last decades. Ongoing studies showed the recent progress of immunotherapy in prostate cancer might be succeeded in China, while prevention remains an important strategy for reducing prostate cancer incidence and mortality.[7,47] Thus, publishing a recommendation for prostate cancer screening and treatment management might still be one of the urgent measures for controlling prostate cancer burden.

Cohort effect represents variations, across groups of individuals born in the same year or years, may arise when each succeeding cohort carries the imprints of physical and social exposures from gestation to old age.[48,49] Fig. 4 showed a slight increase in mortality rates at the age groups 65–69 and 70–74 years for later birth cohorts, which was consistent with previous studies that showed the mortality has not in general declined in elderly persons (65 years or older) over the past decades,[22,50] while the causes might be unknown. Cohort effects on prostate cancer incidence and mortality showed continuous decreasing trends from 1917–1921 to 2002–2006 birth cohort. The probable reason was that more later birth cohorts than earlier birth cohorts received good education and had a stronger awareness of health and disease prevention.[51] More studies reported that industrial waste gas emission or traffic-related air pollution was significantly positively associated with prostate cancer risk of incidence and mortality,[52–54] and a recent study showed air pollution from industrial waste gas emissions is associated with prostate cancer incidences in Shanghai, China.[55] With the development of air pollution control policies from the 1980s onwards, air pollution including total sulfur dioxide (SO_2) emissions, particulate matter ($PM_{2.5}$), and ground level ozone (O_3) was more and more effectively controlled in China.[56,57] In addition, a national survey reported the prevalence rate of experimenting smoking was 47.8% for boys aged 11–20 years in 1998,[58] and the prevalence of smoking was 46.4% among high-school students (from 12 years or younger to 17 years or older) in 2002.[59,60] All of the changes may explain the decreasing cohort trends for incidence and mortality. However, another study reported the prevalence rate of smoking for adolescent males increased from the period 1996–2000 to 2000–2010.[61] Thus, it is controversial that whether the age of adolescent smokers for boys is younger or older since 1990s, which seemingly could not explain the decreasing cohort trends.

Overall, the sharply increasing trend of incidence for China was also observed in Japan from 2008 to 2013,[62] the United States where that of men aged 50–69 years increased from 2004 to 2012,[63] or Panama where higher increases were shown in many cancers from 2001 to 2011[64] and slight decreasing mortality was observed in these countries. However, mortality of prostate cancer began to increase from 2005 to 2017, and both the age and period effect on incidence and mortality showed increasing trends from 1992 through 2017. Despite mortality rates decreasing among all age groups and incidence increasing at a sharp rate, this incidence trend may adversely affect prostate cancer mortality rates.

These findings provided epidemiological evidence to have an understanding on reasons of increasing prostate cancer burden, as well as for the consequent of PSA screening used widely. However, there are some limitations. First, despite the non-bias, validity, asymptotic features, and superior estimation ability of the IE method, the parameter estimates generated using this method are not intuitive. Moreover, the theory behind this method is complicated, and the actual meaning of parameter estimates could not be explained. Second, APC analysis considers a community as the observed and analyzed unit, which might result in ecological fallacies. Thus, we have pointed out scientific hypotheses regarding the causality of these trends of prostate cancer incidence and mortality, based on the available data and existing literature. Third, despite many methods being used to reduce bias, including misclassification corrections, incompleteness, and redistribution of garbage codes, it might be difficult to thoroughly avoid inaccuracy of data. Therefore, our results in the present study on epidemiology of prostate cancer should be treated carefully. Owing to insufficient data, the study could not estimate trends for the incidence and mortality rate between urban and rural China. Thus, epidemiology of prostate cancer in urban and rural areas needs to be further analyzed in the future.

Conclusions

Age effect on both incidence and mortality presented a substantially increasing trend in older people, and period effect showed continuously increasing trends over the past three decades. The percent changes of rates showed incidence rates increased while mortality rates decreased among all age groups. Prostate cancer incidence trend may adversely impact the mortality rates, which is likely to continue to rise in China. Timely intervention should be conducted, especially for earlier birth cohorts at high risk.

Author statements

Ethical approval

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Competing interests

None declared.

Author contributions

X.L. drafted the article. Chuanhua Yu, Yongyi Bi revised the article critically for important intellectual content and gave the final approval of this version to be submitted. Zhi-Jiang Zhang concepted and designed the study.

REFERENCES

1. Torre LA, Bray F, Siegel RL, Ferlay J, Lortet-Tieulent J, Jemal A. Global cancer statistics. CA *Cancer J Clin 2015* 2012;**65**:87–108.
2. Li HZ, Zhang YS. [Review of hot topics in the diagnosis and treatment of prostate cancer in 2016]. *Zhonghua Wai Ke Za Zhi* 2017;**55**:59–62.
3. Center MM, Jemal A, Lortet-Tieulent J, Ward E, Ferlay J, Brawley O, et al. International variation in prostate cancer incidence and mortality rates. *Eur Urol* 2012;**61**:1079–92.
4. Pang C, Guan Y, Li H, Chen W, Zhu G. Urologic cancer in China. *Jpn J Clin Oncol* 2016;**46**:497–501.
5. Wang Y, Liu X, Yan P, Tang J, Chen T, Sun Y, et al. Effect of metformin on the risk of prostate cancer in patients with type 2 diabetes by considering different confounding factors: a meta-analysis of observational studies. *Eur J Cancer Prev* 2019. https://doi.org/10.1097/CEJ.0000000000000514.
6. Ren SC, Chen R, Sun YH. Prostate cancer research in China. *Asian J Androl* 2013;**15**:350–3.
7. Dong DX, Ji ZG. Current progress and controversies in prostate cancer management. *Chin Med J (Engl)*. 2017;**130**:2991–5.
8. Wang L, Yu C, Liu Y, Wang J, Li C, Wang Q, et al. Lung cancer mortality trends in China from 1988 to 2013: new challenges and opportunities for the Government. *Int J Environ Res Public Health* 2016;**13**:E1052.
9. Liu X, Yu C, Wang Y, Bi Y, Liu Y, Zhang ZJ. Trends in the incidence and mortality of diabetes in China from 1990 to 2017: a joinpoint and age-period-cohort analysis. *Int J Environ Res Public Health* 2019;**16**:E158.
10. Wei M, Zhou W, Bi Y, Wang H, Liu Y, Zhang ZJ. Rising mortality rate of cervical cancer in younger women in urban China. *J Gen Intern Med* 2019;**34**:281–4.
11. Liu X, Jiang J, Yu C, Wang Y, Sun Y, Tang J, et al. Secular trends in incidence and mortality of bladder cancer in China, 1990–2017; a joinpoint and age-period-cohort analysis. *Cancer Epidemiol* 2019.
12. Collaborators GBDRF. Global, regional, and national comparative risk assessment of 79 behavioural, environmental and occupational, and metabolic risks or clusters of risks, 1990-2015: a systematic analysis for the Global Burden of Disease Study 2015. *Lancet* 2016;**388**:1659–724.
14. Kim HJ, Fay MP, Feuer EJ, Midthune DN. Permutation tests for joinpoint regression with applications to cancer rates. *Stat Med* 2000;**19**:335–51.
15. Kim HJ, Fay MP, Feuer EJ, Midthune DN. Permutation tests for joinpoint regression with applications to cancer rates. *Stat Med* 2000;**19**:335–51.
16. Clegg LX, Hankey BF, Tiwari R, Feuer EJ, Edwards BK. Estimating average annual per cent change in trend analysis. *Stat Med* 2009;**28**:3670–82.
17. Yang Y. Social inequalities in happiness in the United States, 1972 to 2004: an age-period-cohort analysis. *Am Sociol Rev* 2008;**73**:204–26.
18. Wang L, Yu C, Liu Y, Wang J, Li C, Wang Q, et al. Lung cancer mortality trends in China from 1988 to 2013: new challenges

and opportunities for the government. *Int J Environ Res Public Health* 2016;**13**.
19. Yang Y, Schulhofer-Wohl S, Fu WJJ, Land KC. The intrinsic estimator for age-period-cohort analysis: what it is and how to use it. *Am J Sociol* 2008;**113**:1697–736.
20. Fu WJJ. Ridge estimator in singular design with application to age-period-cohort analysis of disease rates. *Commun Stat-Theor M* 2000;**29**:263–78.
21. Keyes KM, Miech R. Age, period, and cohort effects in heavy episodic drinking in the US from 1985 to 2009. *Drug Alcohol Depend* 2013;**132**:140–8.
22. Qi JL, Wang LJ, Zhou MG, Liu YN, Liu JM, Liu SW, et al. [Disease burden of prostate cancer among men in China, from 1990 to 2013]. *Zhonghua Liuxingbingxue Zazhi* 2016;**37**:778–82.
23. Chen M, Liu W, Tao X. Evolution and assessment on China's urbanization 1960–2010: under-urbanization or over-urbanization? *Habitat Int* 2013;**38**:25–33.
24. daily C. Available from: http://www.gov.cn/zhuanti/xxczh/. [Accessed 15 January 2016].
25. Kanasi E, Ayilavarapu S, Jones J. The aging population: demographics and the biology of aging. *Periodontol* 2000;**72**(2016):13–8.
26. Punnen S, Cooperberg MR. The epidemiology of high-risk prostate cancer. *Curr Opin Urol* 2013;**23**:331–6.
27. Aizer AA, Chen MH, Hattangadi J, D'Amico AV. Initial management of prostate-specific antigen-detected, low-risk prostate cancer and the risk of death from prostate cancer. *BJU Int* 2014;**113**:43–50.
28. Lutz W, Sanderson W, Scherbov S. The coming acceleration of global population ageing. *Nature* 2008;**451**:716–9.
29. Ko J, Falzarano SM, Walker E, Smith KS, Stephenson AJ, Klein EA, et al. Prostate cancer patients older than 70 years treated by radical prostatectomy have higher biochemical recurrence rate than their matched younger counterpart. *Prostate* 2013;**73**:897–903.
30. Salinas CA, Tsodikov A, Ishak-Howard M, Cooney KA. Prostate cancer in young men: an important clinical entity. *Nat Rev Urol* 2014;**11**:317–23.
31. Shahabi A, Corral R, Catsburg C, Joshi AD, Kim A, Lewinger JP, et al. Tobacco smoking, polymorphisms in carcinogen metabolism enzyme genes, and risk of localized and advanced prostate cancer: results from the California Collaborative Prostate Cancer Study. *Cancer Med* 2014;**3**:1644–55.
32. Tang B, Han CT, Gan HL, Zhang GM, Zhang CZ, Yang WY, et al. Smoking increased the risk of prostate cancer with grade group >/= 4 and intraductal carcinoma in a prospective biopsy cohort. *Prostate* 2017;**77**:984–9.
33. Islami F, Moreira DM, Boffetta P, Freedland SJ. A systematic review and meta-analysis of tobacco use and prostate cancer mortality and incidence in prospective cohort studies. *Eur Urol* 2014;**66**:1054–64.
34. Tabayoyong W, Abouassaly R. Prostate cancer screening and the associated controversy. *Surg Clin N Am* 2015;**95**:1023–39.
35. Labrie F. PSA screening for prostate cancer: why so much controversy? *Asian J Androl* 2013;**15**:603–7.
36. Cuzick J, Thorat MA, Andriole G, Brawley OW, Brown PH, Culig Z, et al. Prevention and early detection of prostate cancer. *Lancet Oncol* 2014;**15**:e484–92.
37. Spek A, Szabados B, Roosen A, Stief C. [PSA screening]. *Dtsch Med Wochenschr* 2015;**140**:1435–7.
38. Hankey BF, Feuer EJ, Clegg LX, Hayes RB, Legler JM, Prorok PC, et al. Cancer surveillance series: interpreting trends in prostate cancer–part I: evidence of the effects of screening in recent prostate cancer incidence, mortality, and survival rates. *J Natl Cancer Inst* 1999;**91**:1017–24.
39. Kvale R, Auvinen A, Adami HO, Klint A, Hernes E, Moller B, et al. Interpreting trends in prostate cancer incidence and mortality in the five Nordic countries. *J Natl Cancer Inst* 2007;**99**:1881–7.
40. Draisma G, Etzioni R, Tsodikov A, Mariotto A, Wever E, Gulati R, et al. Lead time and overdiagnosis in prostate-specific antigen screening: importance of methods and context. *J Natl Cancer Inst* 2009;**101**:374–83.
41. Gulati R, Tsodikov A, Etzioni R, Hunter-Merrill RA, Gore JL, Mariotto AB, et al. Expected population impacts of discontinued prostate-specific antigen screening. *Cancer* 2014;**120**:3519–26.
42. Song X. Yinglu Guo: PSA screening test requires wider application in China. *Transl Androl Urol* 2012;**1**:199–201.
43. Kuwahara M, Tochigi T, Kawamura S, Ogata Y, Xu N, Wang H, et al. Mass screening for prostate cancer: a comparative study in Natori, Japan and Changchun, China. *Urology* 2003;**61**:137–41.
44. Ito K. Prostate cancer in Asian men. *Nat Rev Urol* 2014;**11**:197–212.
45. Li M, Na YQ. [The detection rate of prostate cancer in different prostate-specific antigen (PSA) levels in Chinese men]. *Zhonghua Yixue Zazhi* 2008;**88**:16–8.
46. Prostate cancer working group of genitourinary cancer committee in Chinese anti-cancer A. [Consensus of prostate cancer screening]. *Zhonghua Wai Ke Za Zhi* 2017;**55**:340–2.
47. Tian JY, Guo FJ, Zheng GY, Ahmad A. Prostate cancer: updates on current strategies for screening, diagnosis and clinical implications of treatment modalities. *Carcinogenesis* 2018;**39**:307–17.
48. Janssen F, Kunst AE, Demograph NE. Cohort patterns in mortality trends among the elderly in seven European countries, 1950-99. *Int J Epidemiol* 2005;**34**:1149–59.
49. Yang Y. Trends in US adult chronic disease mortality, 1960-1999: age, period, and cohort variations. *Demography* 2008;**45**:387–416.
50. Hansen J. Common cancers in the elderly. *Drugs Aging* 1998;**13**:467–78.
51. Cohen AK, Syme SL. Education: a missed opportunity for public health intervention. *Am J Public Health* 2013;**103**:997–1001.
52. Parent ME, Goldberg MS, Crouse DL, Ross NA, Chen H, Valois MF, et al. Traffic-related air pollution and prostate cancer risk: a case-control study in Montreal, Canada. *Occup Environ Med* 2013;**70**:511–8.
53. Cong XW. Air pollution from industrial waste gas emissions is associated with cancer incidences in Shanghai, China. *Environ Sci Pollut Res* 2018;**25**:13067–78.
54. Garcia-Perez J, Perez-Abad N, Lope V, Castello A, Pollan M, Gonzalez-Sanchez M, et al. Breast and prostate cancer mortality and industrial pollution. *Environ Pollut* 2016;**214**:394–9.
55. Cong X. Air pollution from industrial waste gas emissions is associated with cancer incidences in Shanghai, China. *Environ Sci Pollut Res Int* 2018;**25**:13067–78.
56. Jin Y, Andersson H, Zhang S. Air pollution control policies in China: a retrospective and prospects. *Int J Environ Res Public Health* 2016;**13**.
57. Cai S, Ma Q, Wang S, Zhao B, Brauer M, Cohen A, et al. Impact of air pollution control policies on future PM2.5 concentrations and their source contributions in China. *J Environ Manag* 2018;**227**:124–33.
58. Yang GH, Ma JM, Chen AP, Brown S, Taylor CE, Samet JM. Smoking among adolescents in China: 1998 survey findings. *Int J Epidemiol* 2004;**33**:1103–10.
59. Guo Q, Unger JB, Azen SP, Li CY, Spruijt-Metz D, Palmer PH, et al. Cognitive attributions for smoking among adolescents in China. *Addict Behav* 2010;**35**:95–101.

60. Guo Q, Unger JB, Palmer PH, Chou CP, Johnson CA. The role of cognitive attributions for smoking in subsequent smoking progression and regression among adolescents in China. *Addict Behav* 2013;**38**:1493–8.
61. Han J, Chen XG. A meta-analysis of cigarette smoking prevalence among adolescents in China: 1981-2010. *Int J Environ Res Public Health* 2015;**12**:4617–30.
62. Kimura T, Takahashi H, Okayasu M, Kido M, Inaba H, Kuruma H, et al. Time trends in histological features of latent prostate cancer in Japan. *J Urol* 2016;**195**:1415–20.
63. Hoffman RM, Meisner AL, Arap W, Barry M, Shah SK, Zeliadt SB, et al. Trends in United States prostate cancer incidence rates by age and stage, 1995-2012. *Cancer Epidemiol Biomark Prev* 2016;**25**:259–63.
64. Politis M, Higuera G, Chang LR, Gomez B, Bares J, Motta J. Trend analysis of cancer mortality and incidence in Panama, using joinpoint regression analysis. *Medicine (Baltim)* 2015;**94**:e970.

Appendix A. Supplementary data

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