Cancer Epidemiology 76 (2022) 102068

Contents lists available at ScienceDirect

Cancer Epidemiology

journal homepage: www.elsevier.com/locate/canep

Burden of cancer and changing cancer spectrum among older adults in China: Trends and projections to 2030

Zaixing Shi [a,b,1], Jianlin Lin [a,b,1], Yafei Wu [a,b,c], Sijia Fu [a,b], Yuanyuan Wan [a,b], Ya Fang [a,b,c,*]

[a] State Key Laboratory of Molecular Vaccine and Molecular Diagnostics, School of Public Health, Xiamen University, China
[b] Key Laboratory of Health Technology Assessment of Fujian Province, School of Public Health, Xiamen University, China
[c] National Institute for Data Science in Health and Medicine, Xiamen University, China

ARTICLE INFO

Keywords:
Older adults
Cancer
Incidence
Mortality
Trend
Joinpoint regression

ABSTRACT

Background: Cancer creates considerable challenges for China with its aging population. This analysis aimed to estimate the burden of cancer and transition in cancer spectrum among older adults in China by 2030.
Methods: Using data from the National Central Cancer Registry of China, we estimated annual percent change (APC) in cancer incidence and mortality rates among adults aged 60 years and above between 2006 and 2015 using joinpoint regression. We further estimated the number of new cancer cases and deaths from 2020 to 2030 based on the APC and population projections.
Results: Although cancer incidence and mortality rates have been decreasing among older adults in China between 2006 and 2015, there were marked increases in the incidence and mortality rates of cervical (incidence: APC = 9.2%, mortality: APC = 7.6% all $p < 0.05$) and thyroid cancers (incidence: APC = 9.3%, $p < 0.05$) in older women. Between 2015 and 2030, the number of new cancer cases is projected to increase by 46% from 2.2 million to 3.2 million; cancer deaths will increase by 31% from 1.6 million to 2.1 million among older Chinese adults. In 2015, the 3 most common cancers were lung, colorectal and breast cancer in women, and lung, colorectal and stomach cancer in men. By 2030, cervical cancer is projected to be the most common cancer in women, followed by lung and thyroid cancer; prostate cancer will surpass stomach cancer to become the third most common cancer in men. In both sexes, lung, liver and stomach cancer were the top 3 leading causes of cancer deaths in 2015. In women, cervical cancer will surpass lung cancer as the leading cause of cancer deaths by 2030.
Conclusion: The growing burden of cervical, thyroid and prostate cancer among older Chinese adults represents a major shift in cancer spectrum in this population.

1. Introduction

Over the past 30 years, there were rapid increases in the incidence of lung, breast, colorectal, and prostate cancer, and high incidence of liver, stomach, esophageal, and cervical cancer in China [1,2]. The rising cancer burden in China is likely due to environmental changes associated with industrialization and the adoption of a western lifestyle [3]. However, these factors do not fully explain the cancer trend. For instance, the crude cancer mortality rate increased from 108.3 per 100,000 in 1990–1992–170.1 per 100,000 in 2015, while the age-standardized mortality rate decreased from 94.4 per 100,000 to 77.9 per 100,000 [3]. The opposite trends suggest that the rise of cancer mortality could be attributable to the aging population, as the incidence of most cancers increases dramatically after age 65 [4]. An analysis of the 2012 Global Cancer Observatory suggested that the incidence rate of all cancer among adults aged 65 and above was 1169 per 100,000 in China [5], much higher than the rate for adults aged below 65 years. In addition to population aging, cancer incidence and mortality rates may also change over time. As the proportion of older adults aged 60 years and above in China has increased from 13.3% in 2010 to 18.7% in 2020,

Abbreviations: NCCR, National Cancer Center Registry of China; IARC/IACR, International Agency for Research on Cancer/International Association of Cancer Registries; ICD-10, International Classification of Diseases, 10th revision; ASR, age-standardized rate; APC, annual percent change; HPV, Human papillomavirus; Pap, Papanicolaou; GDP, gross domestic product; HBV, hepatitis B virus; HCV, hepatitis C virus.

* Correspondence to: School of Public Health, Xiamen University, Xiang'an South Road, Xiamen 361102, China.
E-mail address: fangya@xmu.edu.cn (Y. Fang).

[1] These authors contributed equally to this work.

https://doi.org/10.1016/j.canep.2021.102068
Received 18 July 2021; Received in revised form 8 November 2021; Accepted 11 November 2021
Available online 2 December 2021

and is projected to reach 35% by 2050, the cancer burden would increase accordingly [6]. However, few studies have specifically examined how population aging and changing cancer rates impact the future burden of cancer in older Chinese adults and its implications for China's healthcare system.

The joinpoint regression model is frequently used to describe cancer trends [7]. Traditional methods for trend analyses, such as linear regression or time series analysis, assume one model for all data. However, a single model is not flexible enough to capture non-linear trends. In the joinpoint regression, data are divided into several sections, and a linear model is fitted for each section to reveal general trends and turning points [8]. Therefore, it has been widely used in modeling the trends in cancer and other chronic diseases [9].

This study aimed to 1) estimate the trends in cancer incidence and mortality rates between 2006 and 2015 among adults aged 60 years or older in China using the joinpoint regression, and 2) forecast the number of new cancer cases and deaths per year till 2030 among older Chinese adults based on population projection and trend in cancer rates. These analyses have great implications for the planning of cancer prevention strategies and prioritization of cancer research in China.

2. Materials and methods

2.1. Data sources

The analyses used data from the National Cancer Center Registry of China (NCCR) from 2006 to 2015, the best available nationally representative cancer data source in China (http://olap.epsnet.com.cn/). Data on new cancer cases and deaths among adults aged 60 years or older were included in this analysis. The data quality was checked and evaluated according to the International Agency for Research on Cancer/International Association of Cancer Registries (IARC/IACR) and *Guidelines for Chinese Cancer Registration* data-quality criteria [10]. All data in this study were deidentified for public use and there were no ethical issues. All cancer incidence and mortality were classified according to the International Classification of Diseases, 10th revision (ICD-10). We included the following 12 most common cancers in China: cancers of the lung (C33-C34), colorectum (C18-C21), breast (C50), stomach (C16), liver (C22), cervix (C53), esophagus (C15), thyroid (C73), brain/CNS (C70-C72), pancreas (C25), lymphoma (C81-C85, C88, C90, C96), and leukemia (C91-C95).

2.2. Statistical analysis

We analyzed the trends of age-specific incidence and mortality rate from 2006 to 2015 using the joinpoint model based on the log-transformed rates (per 100,000 population). We described the age-specific cancer trends using the annual percent change (APC) and tested if the APC is statistically different from zero using the Z test. An upward trend is defined as an APC > 0, a downward trend is defined as an APC < 0. A trend was considered stable if the p-value for the APC was 0.05. If the linearity assumption was not met, the trend was estimated in segments. Cancer incidence and mortality rates in 2020–2030 were estimated based on the rates in 2015 and the latest APC over 2006–2015. Finally, we obtained the estimated population size for adults aged 60 years and above in China from the United Nations World Population Prospects 2019 under the medium-fertility variant assumption [11]. The trend parameters were estimated for each 5-year age group (60–64, 65–69, 70–74, 75–79, 80–84, 85+ years) and stratified by sex. For year i, the total new cancer cases and deaths were calculated as the sum of J age-specific estimates:

$$Cancer\ cases_i = \sum_{j=1}^{J} (Incidence\ rate_{ij} \times Population\ size_{ij})$$

$$Cancer\ deaths_i = \sum_{j=1}^{J} (Mortality\ rate_{ij} \times Population\ size_{ij})$$

We forecasted the number of new cancer cases and deaths under two scenarios: a "constant rate" scenario in which the incidence and mortality rates were assumed constant over time, and a "continuous trend" scenario in which the rates were assumed changing at the estimated APC. The "constant rate" scenario would demonstrate the effect of the foreseeable demographic changes on cancer burden, whereas the "continuous trend" scenario would demonstrate the combined effect of changing demographics and cancer spectrum. Data collection and management were conducted in Microsoft Office Excel and R (R Core Team, 2020). Model fitting was performed in the National Cancer Institute's Joinpoint Regression Program (version 4.6.0.0). $P < 0.05$ was regarded as statistically significant.

3. Results

3.1. Trends in cancer incidence and mortality rates, 2006–2015

The overall cancer incidence rate showed a downward trend during 2006–2015, with rates consistently higher in men than that in women (Fig. 1). For older women, colorectum, stomach, esophagus, liver, and pancreas cancers decreased (all $p < 0.05$). However, the incidence rate of cervical (APC = 9.2%) and thyroid cancer (APC = 9.3%) showed rapid increases in women (all $p < 0.05$). The increase in the incidence rate of cervical cancer was observed for all age groups, whereas the increase in thyroid cancer primarily affected those aged between 60 and 79 years (Fig. 2). For older men, incidence rates of all cancers showed rapid decreases after 2011 (APC = −1.1%, $p < 0.05$), mostly driven by the reduction in liver, colorectal and esophageal cancer. Incidence rate of thyroid cancer increased dramatically in men (APC = 8.7%, $p < 0.05$). Incidence rate of prostate appeared to be declining among all men; however, it increased by 15.5% annually in those aged 60–64 years (Fig. 2). For both women and men, the decreases in cancer incidence rate were more pronounced in rural than urban areas (Supplemental Fig. 1A).

A decreasing trend in the overall cancer mortality rate has been observed for women and men (Fig. 3). For older women, mortality rate of cervical cancer has been steadily increasing at a high rate (APC = 7.6%, $p < 0.05$; Fig. 1), and the rate has been increasing in all age groups. For older men, the overall cancer mortality rate started to decline after 2011 (APC = −1.5%, $p < 0.05$), especially for esophageal cancer, which showed significant change in direction (APC for 2006–2011: 4.9%, APC for 2011–2015: −4.1%, all $p < 0.05$). Mortality rate of prostate cancer has increased for those age between 60 and 69 years (APC = 4.0%, $p < 0.05$; Fig. 2). Rural areas showed a greater reduction in overall cancer mortality rate than urban areas, although the rate remained higher in rural areas (Supplemental Fig. 1B).

3.2. Predicted new cancer cases and deaths by 2030

Under the "constant rate" scenario which was solely based on population projections, there would be 3,646,249 new cancer cases and 2,645,130 cancer deaths among older Chinese adults in 2030, equivalent to a 66% increase in new cancer cases and a 68% increase in cancer deaths compared to 2015. Under the "continuous trend" scenario, based on changing cancer rates and population projections, there would be 3,212,269 (95% CI: 2,840,665–3,657,562) new cancer cases and 2,074,268 (95% CI: 1,790,484–2,499,854) cancer deaths among older Chinese adults in 2030, equivalent to a 46% increase in new cancer cases and a 31% increase in cancer deaths compared to 2015. Of note, the predicted number of cancer cases and deaths were much higher than what would be expected under the "constant rate" scenario for cervical, thyroid, prostate, colorectal cancer, and lymphoma (Tables 1–2).

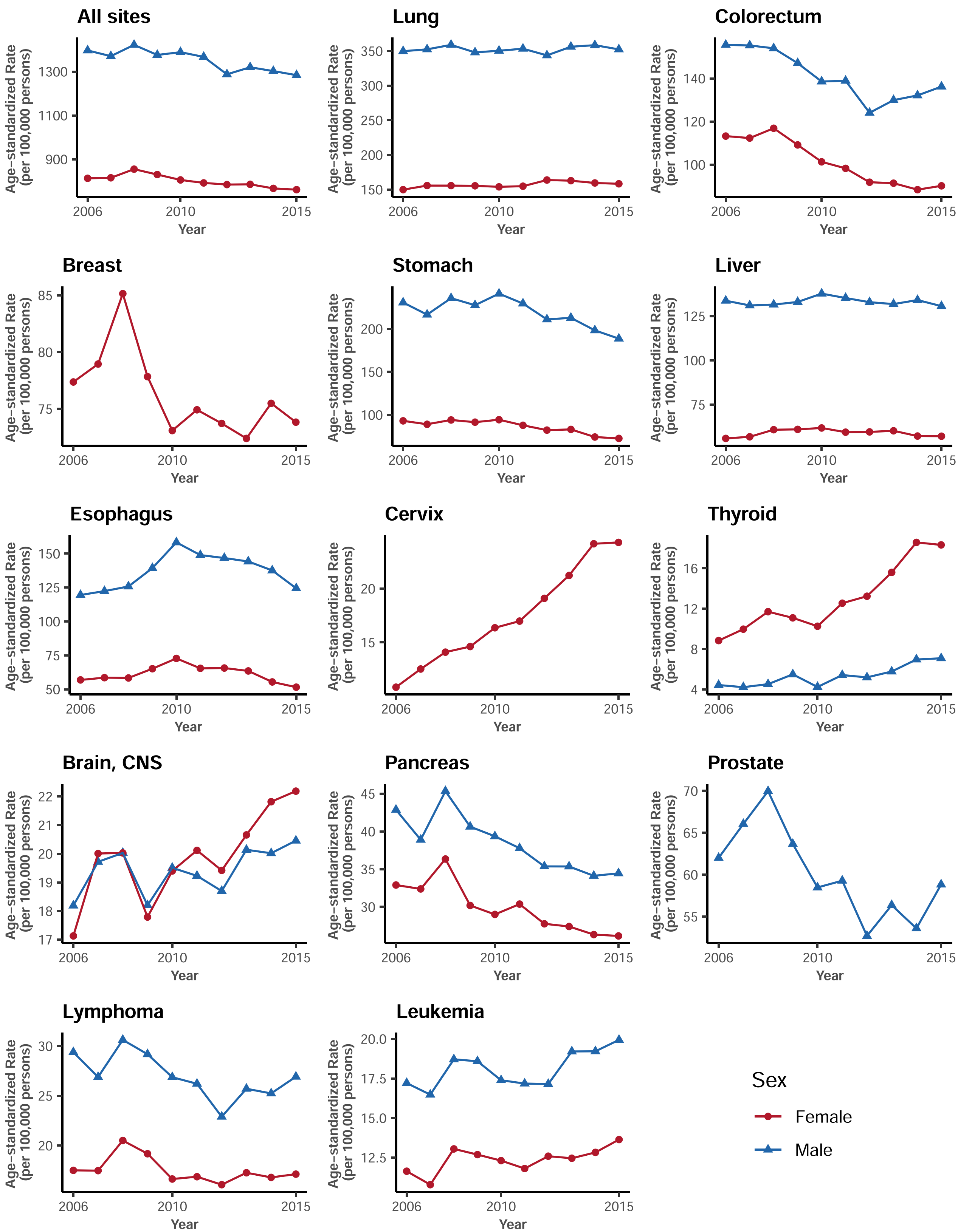

Fig. 1. Trends in incidence rates of common cancer among older adults in China, 2006–2015.

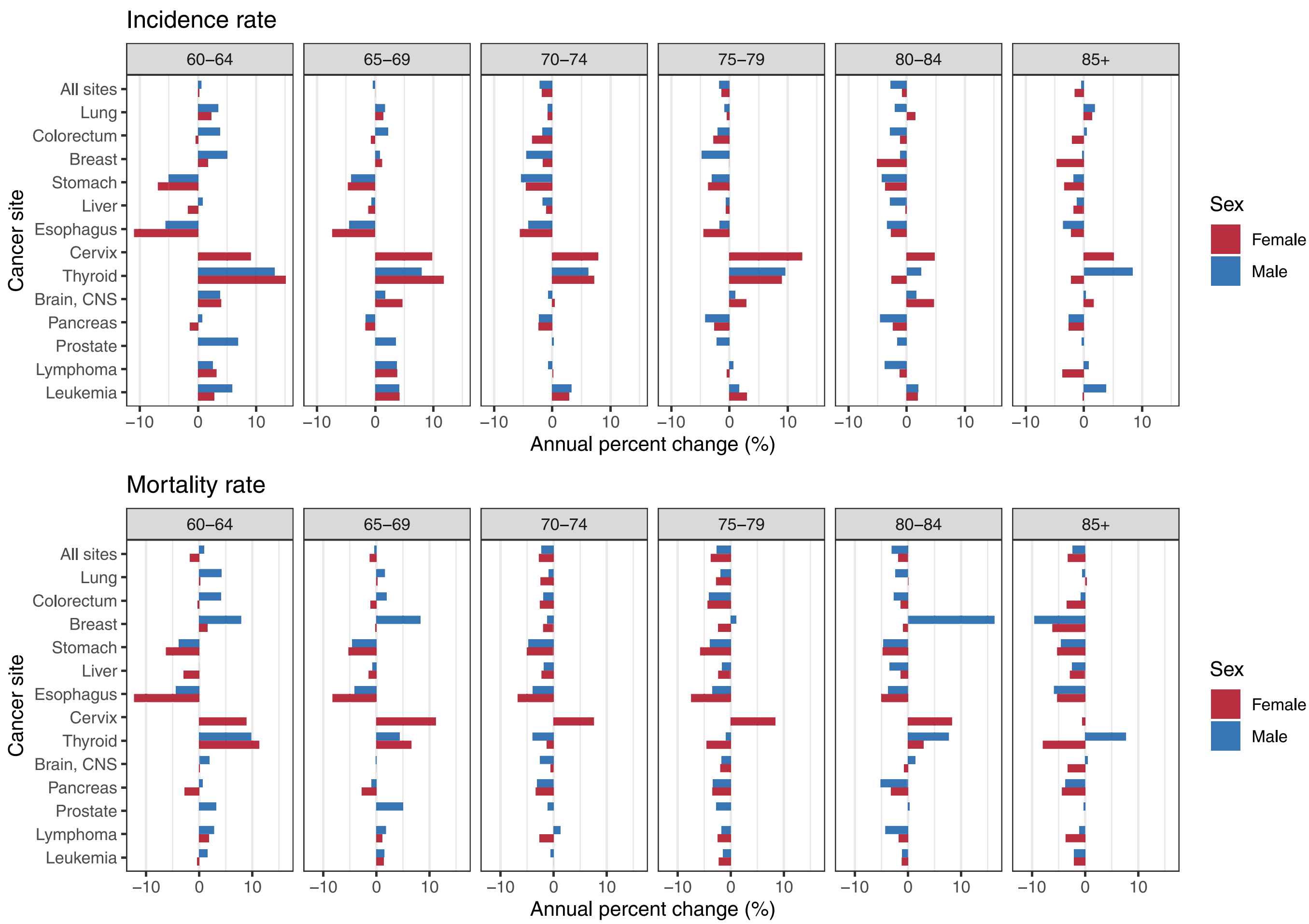

Fig. 2. Age-specific annual percent change in cancer incidence rates (A) and mortality rates (B) for common cancers in women and men among older adults in China, 2006–2015.

3.3. Predicted changes in cancer spectrum by 2030

The "continuous trend" analysis suggested significant changes in the spectrum of cancer among older adults. In 2015, women's top 3 most commonly diagnosed cancers were lung, colorectal, and breast cancer (Table 1, Fig. 4). With dramatically increased cervical (+973%) and thyroid cancer (+1050%) incidences, cervical cancer will become the most common cancer in women by 2030, followed by lung and thyroid cancers (Table 1, Fig. 4). For men, lung, stomach, and colorectal cancer were the most common cancers in 2020. We predicted substantial increases in prostate cancer incidence between 2020 and 2030 (+517%), which will surpass colorectal cancer to become the third most common male cancer in 2030 (Table 1, Fig. 4). In 2015, lung, liver, and stomach cancers were the top 3 causes of cancer deaths among women and men (Table 2, Fig. 5). By 2030, cervical cancer will surpass lung cancer as the leading cause of cancer deaths in women (+1845%) (Table 2, Fig. 5).

4. Discussion

Based on population aging and the cancer trends among older adults in China between 2006 and 2015, the number of new cancer cases is expected to increase from 2.2 million in 2015–3.2 million in 2030 (+46%), and cancer deaths will increase to 2.1 million in 2030 (+31%). The expected increases were lower than predictions based on population aging alone, suggesting aging-related increases in cancer burden would be alleviated if the current decreasing trend in cancer incidence and mortality rate continues. In addition, cervical and thyroid cancer were estimated to become the first and second most common cancer diagnoses in older women, and cervical cancer will be the leading cause of cancer death in women by 2030. Prostate cancer will rise to the third most common cancer and fourth leading cancer death for older men by 2030. Therefore, cancer prevention is critically needed to address the increased burden of cervical, thyroid and prostate cancer in older Chinese.

Our findings contribute to the growing body of literature suggesting a rapidly growing burden of cancer among older adults worldwide. Pilleron et al. predicted the increase in new cancer cases between 2012 and 2035 in older adults aged 65 years and above worldwide [5]. They suggested that the world's less developed regions will see greater increases in new cancer cases (+144%) compared to more developed regions (+54%), with the biggest increase in the Middle East and Northern Africa (+157%), and in China (+155%). However, their forecasts were based on the GLOBOCAN 2012 data only, which may provide incomplete cancer statistics for China. Further, the study assumed the incidence rates in 2012 to be constant till 2035, which is unlikely. Using cancer registry data from the NCCR, our analysis estimated the future cancer burden based on population aging and changing cancer rates, providing more realistic predictions. Because the incidence of cancer among older adults in China (1169/100,000) is higher compared to other Asian countries (Asia excluding China and India: 976/100,000, India: 445/100,000) [5], it is important to develop cancer prevention efforts to curb the growing cancer burden older adults in China. Considering the high prevalence of comorbidity in older adults, the declined physical function, and the limitation in cancer treatment due to low tolerance of adverse effects, more resources are needed to adequately address the need for cancer treatment and care in older

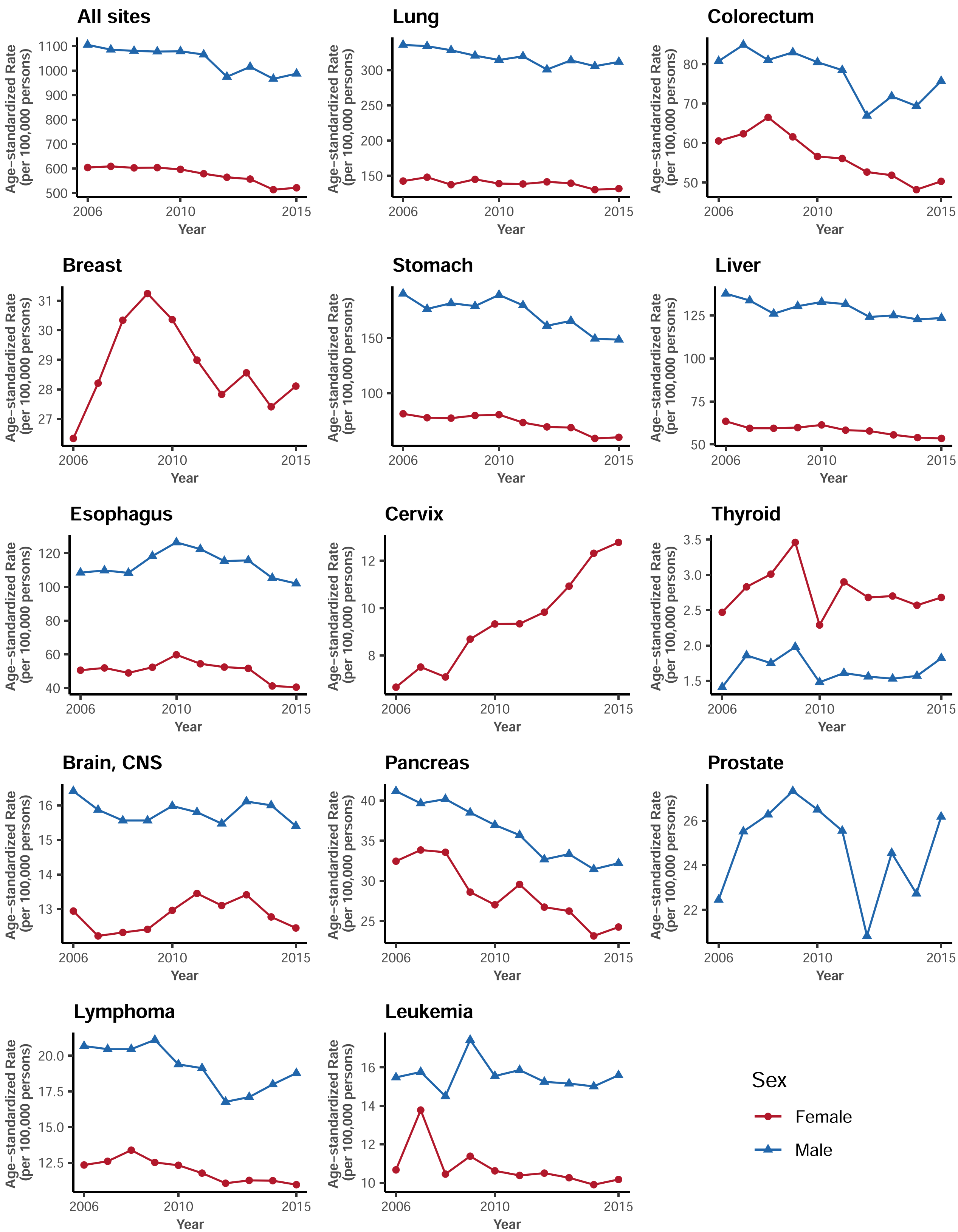

Fig. 3. Trends in mortality rates of common cancer among older adults in China, 2006–2015.

Table 1
Comparison of estimated cancer cases in 2030 under the “constant rate” and “continuous trend” scenarios.

Sex	Site	ICD-10 code	New cancer cases, 2015	Rank, 2015	New cancer cases, 2030 (constant rate)	New cancer cases, 2030 (continuous trend)	Rank, 2030 (continuous trend)	Percent change, 2015–2030 (continuous trend)
Women	Lung	C33-C34	207,172	1	300,457	470,929	2 ↓	127%
	Colorectum	C18-C21	102,124	2	171,641	121,205	6 ↓	19%
	Breast	C50	94,951	3	141,279	132,948	4 ↓	40%
	Stomach	C16	76,484	4	138,031	79,955	8 ↓	5%
	Liver	C22	69,058	5	108,506	125,691	5 ↔	82%
	Cervix	C53	50,794	6	46,633	544,976	1 ↑	973%
	Esophagus	C15	47,917	7	98,065	45,683	10 ↓	-5%
	Thyroid	C73	40,092	8	34,910	461,127	3 ↑	1050%
	Brain, CNS	C70-C72	33,057	9	42,365	99,639	7 ↑	201%
	Pancreas	C25	28,538	10	49,438	33,755	12 ↓	18%
	Lymphoma	C81-C85, C88, C90, C96	22,317	11	32,940	38,850	11 ↓	74%
	Leukemia	C91-C95	20,921	12	26,121	74,245	9 ↑	255%
Men	Lung	C33-C34	416,369	1	603,425	802,768	1 ↔	93%
	Stomach	C16	179,481	2	324,871	168,893	5 ↓	-6%
	Colorectum	C18-C21	175,764	3	232,974	574,317	2 ↑	227%
	Liver	C22	150,965	4	224,613	236,035	4 ↔	56%
	Esophagus	C15	125,571	5	214,653	166,346	6 ↓	32%
	Prostate	C61	69,058	6	97,825	425,955	3 ↑	517%
	Lymphoma	C81-C85, C88,C90, C96	35,908	7	46,381	149,163	7 ↔	315%
	Pancreas	C25	35,791	8	58,656	42,136	11 ↓	18%
	Leukemia	C91-C95	26,678	9	34,042	82,105	9 ↔	208%
	Brain, CNS	C70-C72	25,858	10	35,254	57,640	10 ↔	123%
	Thyroid	C73	12,911	11	12,349	117,740	8 ↑	812%

Abbreviations: CNS, central nervous system.
Arrows indicate the direction of change in ranking from 2015 to 2030: ↓, lower rank; ↔, same rank; ↑, higher rank.

Table 2
Comparison of estimated cancer deaths in 2030 under the “constant rate” and “continuous trend” scenarios.

Sex	Site	ICD-10 code	Cancer deaths, 2015	Rank, 2015	New cancer deaths, 2030 (constant rate)	New cancer deaths, 2030 (continuous trend)	Rank, 2030 (continuous trend)	Percent change, 2015–2030 (continuous trend)
Women	Lung	C33-C34	154,351	1	247,917	287,624	2 ↓	86%
	Liver	C22	61,441	2	100,979	86,401	3↓	41%
	Stomach	C16	58,461	3	112,311	50,080	6 ↓	-14%
	Colorectum	C18-C21	52,169	4	93,074	59,973	4 ↔	15%
	Esophagus	C15	34,970	5	76,001	26,077	8 ↓	-25%
	Breast	C50	34,082	6	52,667	51,940	5 ↑	52%
	Cervix	C53	26,715	7	24,277	519,679	1 ↑	1845%
	Pancreas	C25	25,069	8	45,659	25,705	9 ↓	3%
	Brain, CNS	C70-C72	15,585	9	23,585	27,779	7 ↑	78%
	Lymphoma	C81-C85, C88,C90, C96	13,044	10	20,869	19,478	10 ↔	49%
	Leukemia	C91-C95	12,017	11	19,336	18,372	11 ↔	53%
	Thyroid	C73	3645	12	5,028	14,230	12 ↑	290%
Men	Lung	C33-C34	375,195	1	528,366	979,826	1 ↔	161%
	Stomach	C16	143,815	2	252,177	144,596	4 ↓	1%
	Liver	C22	139,151	3	211,175	205,484	3 ↔	48%
	Esophagus	C15	95,219	4	173,612	82,501	5 ↓	-13%
	Colorectum	C18-C21	86,149	5	125,028	275,938	2 ↑	220%
	Pancreas	C25	32,292	6	54,568	35,159	8 ↓	9%
	Prostate	C61	25,196	7	40,397	52,389	7 ↔	108%
	Lymphoma	C81-C85, C88,C90, C96	22,203	8	31,942	57,933	6 ↑	161%
	Leukemia	C91-C95	17,953	9	26,424	33,751	9 ↔	88%
	Brain, CNS	C70-C72	17,085	10	26,195	28,201	10 ↔	65%
	Thyroid	C73	2208	11	3029	8268	11 ↔	275%

Abbreviations: CNS, central nervous system.
Arrows indicate the direction of change in ranking from 2015 to 2030: ↓, lower rank; ↔, same rank; ↑, higher rank.

adults.

Cervical cancer is projected to be the most commonly diagnosed cancer among older Chinese women. Human papillomavirus (HPV) infection is a major cause of cervical cancer [12,13]. A recent study in China suggested that approximately 110,000 new cancer cases and 36, 000 cancer deaths were attributable to HPV infection in 2015, of which

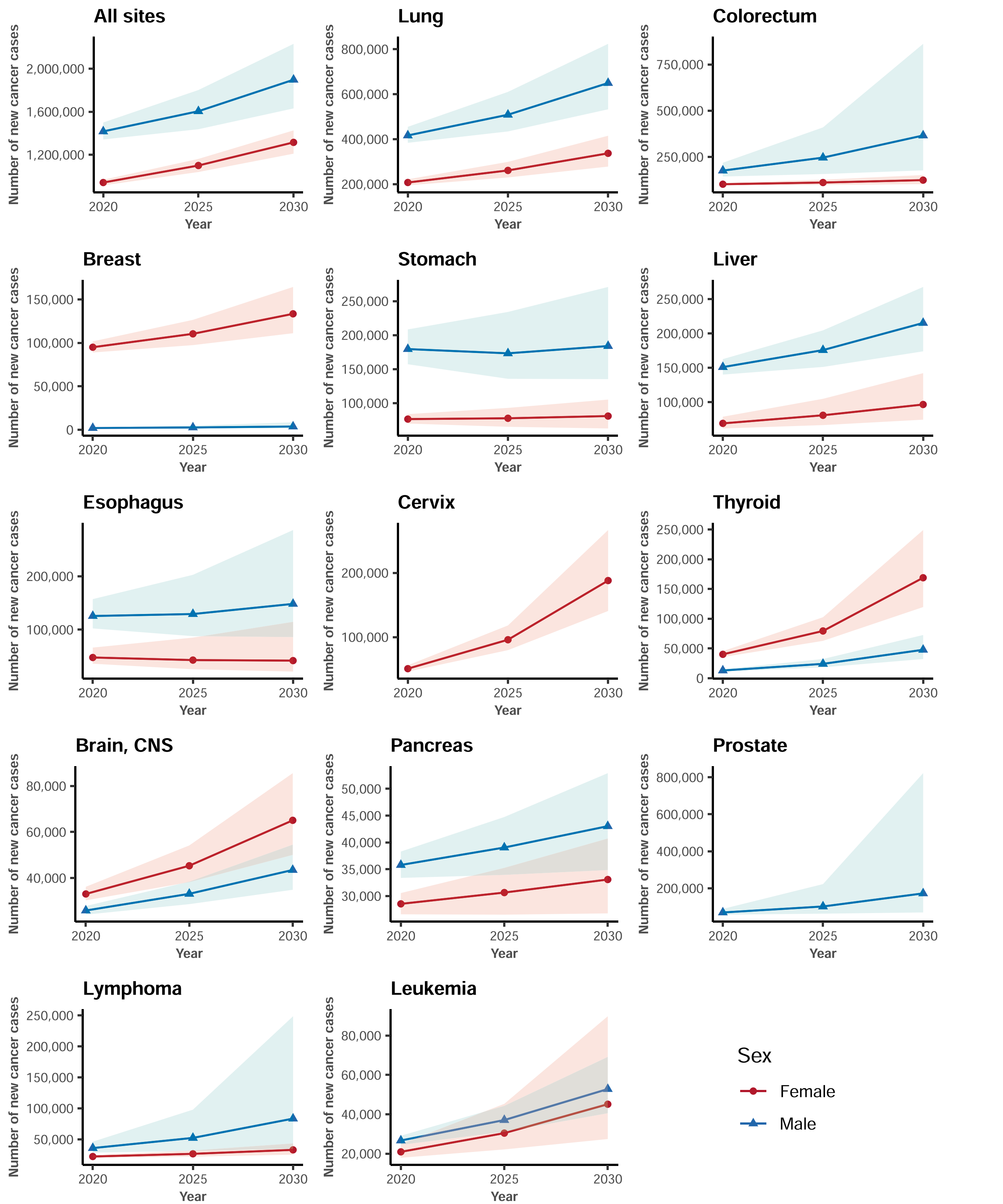

Fig. 4. Predicted number of new cases for common cancers by sex in China, 2020–2030.

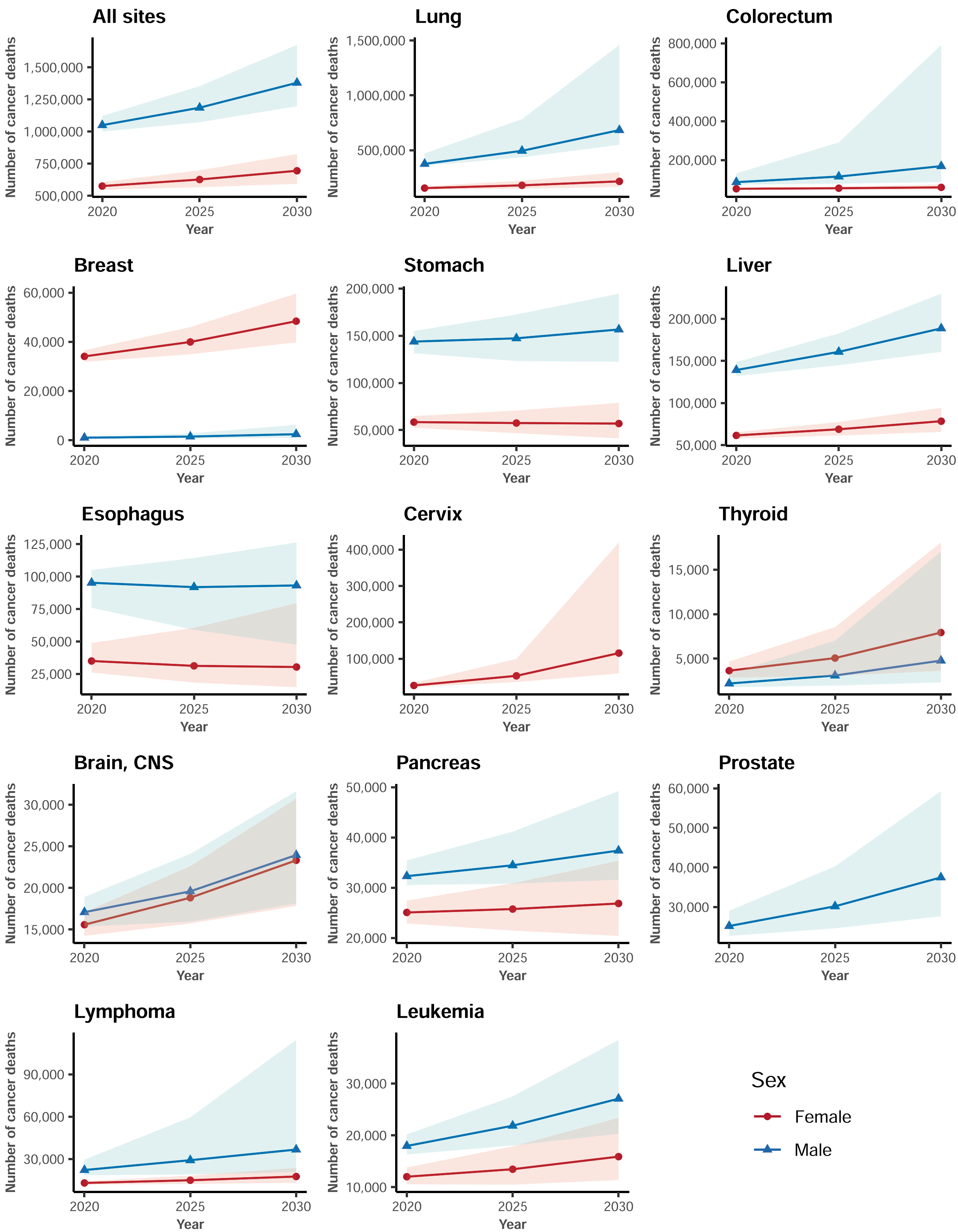

Fig. 5. Predicted number of deaths for common cancers by sex in China, 2020–2030.

cervical cancer accounted for 86% of HPV-related cancer cases and 78% of the HPV-related cancer deaths, respectively [14]. Recently, the HPV vaccine has been shown to reduce 75%–97% of cervical neoplasia among girls vaccinated before age 16, suggesting an apparent efficacy for preventing cervical cancer [14,15]. In the US countries where HPV vaccines have been widely adopted, the overall incidence of cervical cancer showed a downward trend during 1953–2012, while the rate showed an upward trend in China during the same time [16]. The rate of HPV vaccination was only 9.4% among adolescents aged 16–18 years in China in 2019 [17,18], much lower than that in the US (75.1%) [19]. Furthermore, the high burden of cervical cancer in China could be due to the lack of the Papanicolaou (Pap) test for cervical cancer screening, only 20% of Chinese women have ever received a Pap test, lower than the rate among American women (64.6%) [20–22]. Evidence from western countries showed benefits of cervical cancer screening. The UK has implemented a national screening program for cervical cancer, and an estimated 65,000 cases (48%) of expected cancers have been prevented from 1998 to 2013 [23]. Considering that China has just begun to popularize HPV vaccination and Pap test, it may take years before they can effectively reverse the increasing trend in cervical cancer. Therefore, the incidence and mortality rates of cervical cancer may continue to increase in the near future.

We also predict significant increases in thyroid cancer among older women in the coming decades. This finding is consistent with that observed in other studies among Chinese adults [20,24]. Although the increase may be due to overdiagnosis through the wide use of new imaging technologies in assessing thyroid diseases, including ultrasound, computed tomography, and magnetic resonance imaging. Unfortunately, it is difficult to test this hypothesis in our analysis because the cancer stage is not available in the NCCR registry data. Several studies of thyroid cancer trends in China suggest that excessive iodine intake may have partly contributed to the rapid increase in the incidence of thyroid cancer and other thyroid diseases [25].

Consistent with previous reports, we showed that the incidence and mortality of prostate cancer were increasing in China over the past decade. Gu et al. reported that the age-standardized incidence rate of prostate cancer in China increased from 3.9/100000 in 2000–10.65/100000 in 2014. The increasing trend was more pronounced in rural areas, with an APC of 12.3% between 2000 and 2005 and 4.8% between 2005 and 2014 [26]. Our study contributes to the literature by showing that the rates increased most dramatically in those aged 60–64 years (APC = 15.5% for incidence, APC = 4.2% for mortality). This finding is comparable to a previous analysis of prostate cancer trends using the Global Burden of Disease (GBD) 2017 data, which showed that the incidence rate of prostate cancer increased most rapidly among those aged 50–64 years between 1990 and 2017 (APC = 3.99%–4.06%) [27]. Although the exact reason behind the upward trend in prostate cancer remains unclear, it is likely due to the increasing prostate-specific antigen (PSA) screening and early diagnosis in China [28]. Nevertheless, the growing burden of prostate cancer deaths still calls for effective prevention and treatment for older adults in China.

Our results suggest that cancer incidence and mortality were generally higher in rural residents, although the gap has been dramatically narrowed during 2006–2015. The higher smoking rate in rural populations could be the primary contributor to the urban/rural disparity since smoking-related cancers account for about 75% of all cancers combined in China. The fact that cancer incidence and mortality have been decreasing at a greater rate in the rural area in China suggests practical cancer prevention efforts and improved healthcare resources directed at the rural area.

In this study, nationally representative data were used to analyze cancer incidence and mortality for the older Chinese, providing reliable estimates of China's cancer trends. In addition, the joinpoint model used in our study is robust to detecting non-linear changes in cancer trends, making the estimation more reasonable. Our forecast of future cancer burden was able to provide two sets of estimates, one based on the demographic change only and one based on the combined effect of population aging and trend in cancer rates among older adults. These estimates offer a corridor of the true cancer burden and may be used as a basis for health economic evaluation of future medical care needs and the allocation of resources in China.

Our analyses have several limitations. First, although we estimated the cancer incidence and mortality in 2020 based on the NCCR data, there was still uncertainty in estimation due to the varying number of registered areas each year and the completeness and validity of certain cancer registries. Second, the high projections for cervical and thyroid cancer incidence may be overestimated. For example, even if there will be no progress in cervical cancer screening or HPV vaccination coverage in China, it is unlikely that the recent rise in cervical cancer incidence will go on forever. It is almost certain that the current trends will at least be attenuated at some point. Finally, cancer registration remains challenging in the face of population migration in China. As such, geographical information for cancer patients is usually based on the usual residence rather than treatment areas.

5. Conclusions

In summary, this analysis suggests an overall decreasing trend in cancer incidence and mortality among older adults in China between 2006 and 2015. However, there were rapid increases in cervical, thyroid, and prostate cancer. With the combined results of population aging and the changing cancer spectrum, we predict that cancer incidences and deaths will increase by 46%–66% and 31%–68% between 2015 and 2030, respectively. In addition, the new cases and deaths of cervical, thyroid, and prostate cancer are projected to increase dramatically, ranking among the top 5 most common and deadly cancers in older adults in 2030. Finally, cancer incidence and mortality remain higher in rural China, calling for more cancer prevention efforts and medical resources for those living in disadvantaged areas.

Funding

This work was supported by the National Natural Science Foundation of China [grant numbers 81973144 and 82103951] and Xiamen University Graduate Studies Fieldwork Fund [grant number 2019GF032].

CRediT authorship contribution statement

Zaixing Shi: Conceptualization, Methodology, Formal analysis, Validation, Visualization, Writing – original draft, Writing – review & editing, Supervision. **Jianlin Lin:** Methodology, Data curation, Formal analysis, Validation, Visualization, Writing – original draft, Writing – review & editing. **Yafei Wu:** Data curation, Formal analysis, Writing – original draft. **Sijia Fu:** Data curation. **Yuanyuan Wan:** Data curation. **Ya Fang:** Conceptualization, Funding acquisition, Writing – review & editing, Supervision.

Conflict of interest

The authors declare no conflict of interest.

Acknowledgment

The data used in this study were obtained from the Annual Report on Status of Cancer in China. We thank the National Central Cancer Registry (NCCR) of China for providing the data.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.canep.2021.102068.

References

[1] D. Sun, et al., Cancer burden in China: trends, risk factors and prevention, Cancer Biol. Med. 17 (4) (2020) 879–895, https://doi.org/10.20892/j.issn.2095-3941.2020.0387.

[2] H. Qiu, S. Cao, R. Xu, Cancer incidence, mortality, and burden in China: a time-trend analysis and comparison with the United States and United Kingdom based on the global epidemiological data released in 2020, Cancer Commun. 41 (10) (2021) 1037–1048, https://doi.org/10.1002/cac2.12197.

[3] W. Chen, et al., Cancer statistics in China, 2015, CA Cancer J. Clin. 66 (2) (2016) 115–132, https://doi.org/10.3322/caac.21338.

[4] M.C. White, et al., Age and cancer risk: a potentially modifiable relationship, Am. J. Prev. Med. 46 (3 Suppl 1) (2014) S7–S15, https://doi.org/10.1016/j.amepre.2013.10.029.

[5] S. Pilleron, et al., Global cancer incidence in older adults, 2012 and 2035: a population-based study, Int. J. Cancer 144 (1) (2019) 49–58, https://doi.org/10.1002/ijc.31664.

[6] United Nations,Department of Economic and Social Affairs, Population Division, in: United Nations (Ed.), World Population Ageing 2019 (ST/ESA/SER.A/444)., United Nations, 2020.

[7] F. Bray, A. Jemal, N. Grey, J. Ferlay, D. Forman, Global cancer transitions according to the Human Development Index (2008-2030): a population-based study, Lancet Oncol. 13 (8) (2012) 790–801, https://doi.org/10.1016/S1470-2045(12)70211-5.

[8] H.J. Kim, M.P. Fay, E.J. Feuer, D.N. Midthune, Permutation tests for joinpoint regression with applications to cancer rates, Stat. Med. 19 (3) (2000) 335–351, 10.1002/(sici)1097-0258(20000215)19:3<335::aid-sim336>3.0.co;2-z.

[9] K.K. Tsoi, H.W. Hirai, F.C. Chan, S. Griffiths, J.J. Sung, Cancer burden with ageing population in urban regions in China: projection on cancer registry data from World Health Organization, Br. Med. Bull. 121 (1) (2017) 83–94, https://doi.org/10.1093/bmb/ldw050.

[10] Ferlay, J., Burkhard, C., Whelan, S., Parkin, D., 2005. Check and Conversion Programs for Cancer Registries (IARC/IACR Tools for Cancer Registries), IARC technical Report No. 42, IARC Press, Lyon, France.

[11] C. Global Burden of Disease Cancer, et al., Global, regional, and national cancer incidence, mortality, years of life lost, years lived with disability, and disability-adjusted life-years for 29 cancer groups, 1990 to 2017: a systematic analysis for the Global Burden of Disease Study, JAMA Oncol. 5 (12) (2019) 1749–1768, https://doi.org/10.1001/jamaoncol.2019.2996.

[12] M. Vonsky, et al., Carcinogenesis associated with Human Papillomavirus Infection. Mechanisms and potential for immunotherapy, Biochemistry 84 (7) (2019) 782–799, https://doi.org/10.1134/S0006297919070095.

[13] C. de Martel, M. Plummer, J. Vignat, S. Franceschi, Worldwide burden of cancer attributable to HPV by site, country and HPV type, Int. J. Cancer 141 (4) (2017) 664–670, https://doi.org/10.1002/ijc.30716.

[14] U.A. Hvidtfeldt, et al., Long-term low-level ambient air pollution exposure and risk of lung cancer – a pooled analysis of 7 European cohorts, Environ. Int. 146 (2021), 106249, https://doi.org/10.1016/j.envint.2020.106249.

[15] M. Falcaro, et al., The effects of the national HPV vaccination programme in England, UK, on cervical cancer and grade 3 cervical intraepithelial neoplasia incidence: a register-based observational study, Lancet (2021), https://doi.org/10.1016/S0140-6736(21)02178-4.

[16] J. Wang, Z. Bai, Z. Wang, C. Yu, Comparison of secular trends in cervical cancer mortality in China and the United States: an age-period-cohort analysis, Int. J. Environ. Res. Public Health 13 (11) (2016), https://doi.org/10.3390/ijerph13111148.

[17] S.K. Kjaer, C. Dehlendorff, F. Belmonte, L. Baandrup, Real-world effectiveness of Human Papillomavirus Vaccination against cervical cancer, J. Natl. Cancer Inst. 113 (10) (2021) 1329–1335, https://doi.org/10.1093/jnci/djab080.

[18] D. You, et al., Human Papillomavirus (HPV) Vaccine uptake and the willingness to receive the HPV vaccination among female college students in china: a multicenter study, Vaccines 8 (1) (2020), https://doi.org/10.3390/vaccines8010031.

[19] C. Pingali, et al., National, regional, state, and selected local area vaccination coverage among adolescents aged 13-17 years – United States, 2020, MMWR Morb. Mortal. Wkly. Rep. 70 (35) (2021) 1183–1190, https://doi.org/10.15585/mmwr.mm7035a1.

[20] L. Zhao, et al., Features and trends of thyroid cancer in patients with thyroidectomies in Beijing, China between 1994 and 2015: a retrospective study, BMJ Open 9 (1) (2019), e023334, https://doi.org/10.1136/bmjopen-2018-023334.

[21] F.H. Zhao, et al., Prevalence of human papillomavirus and cervical intraepithelial neoplasia in China: a pooled analysis of 17 population-based studies, Int. J. Cancer 131 (12) (2012) 2929–2938, https://doi.org/10.1002/ijc.27571.

[22] K.L. MacLaughlin, et al., Trends over time in Pap and Pap-HPV cotesting for cervical cancer screening, J. Women's Health 28 (2) (2019) 244–249, https://doi.org/10.1089/jwh.2018.7380.

[23] F. Pesola, P. Sasieni, Impact of screening on cervical cancer incidence in England: a time trend analysis, BMJ Open 9 (1) (2019), e026292, https://doi.org/10.1136/bmjopen-2018-026292.

[24] L. Du, et al., Thyroid cancer: trends in incidence, mortality and clinical-pathological patterns in Zhejiang Province, Southeast China, BMC Cancer 18 (1) (2018) 291, https://doi.org/10.1186/s12885-018-4081-7.

[25] E.G. Koukkou, N.D. Roupas, K.B. Markou, Effect of excess iodine intake on thyroid on human health, Minerva Med. 108 (2) (2017) 136–146, https://doi.org/10.23736/S0026-4806.17.04923-0.

[26] X.Y. Gu, et al., [Analysis on the trend of prostate cancer incidence and age change in cancer registration areas of China, 2000 to 2014], Zhonghua Yu Fang Yi Xue Za Zhi 52 (6) (2018) 586–592, https://doi.org/10.3760/cma.j.issn.0253-9624.2018.06.006.

[27] X. Liu, C. Yu, Y. Bi, Z.J. Zhang, Trends and age-period-cohort effect on incidence and mortality of prostate cancer from 1990 to 2017 in China, Public Health 172 (2019) 70–80, https://doi.org/10.1016/j.puhe.2019.04.016.

[28] A. Prostate, Cancer Working Group of Genitourinary Cancer Committee in Chinese Anti-Cancer, [Consensus of prostate cancer screening], Zhonghua Wai Ke Za Zhi 55 (5) (2017) 340–342, https://doi.org/10.3760/cma.j.issn.0529-5815.2017.05.005.